PLANT BIOLOGY.

A TEXT-BOOK OF ELEMENTARY BOTANY ARRANGED FOR MODERN METHODS OF TEACHING.

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PLANT BIOLOGY.

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PREFACE.

THIS book has been prepared to satisfy the requirements of teachers who prefer modern methods of work. It is based largely upon the courses in elementary Botany, which I have organised and conducted for several years in classes consisting chiefly of Day Training College students. These elementary students have usually very little previous knowledge of Science, and I have found it advisable to devote some time to the physical and chemical properties of air, water, and soil when dealing with the physiology of plants and their adaptations to surroundings. Since the work in these "junior" classes has been of an essentially practical character, it has been necessary to repeat each lesson several times a week in order to keep each class small enough for thoroughly satisfactory work to be done Rarely have I taken more than a dozen students at a time with a larger number it becomes difficult to supervise each student's observations and experiments. The division of classes and repetition of each lesson have made the work very heavy, but my firm conviction that the elements of Plant Biology can only be taught successfully by discarding formal lectures, by giving the foremost place to Physiology and Ecology, and by insisting upon actual observations, experiments, and the making of notes and

sketches by each student, has been confirmed by the many letters I have received from former students who have followed up their work in Plant Biology after leaving college and taking up teaching, and who have applied the same practical methods in their classes of school-children.

I have introduced as few technical terms as possible, and have only used such terms as are useful in avoiding tiresome repetition of equivalent phrases or compound words. I have also tried to write the book in such a way as to render it of comparatively little use to the misguided type of student, with whom all science-instructors are familiar and who, taking the line of least resistance, desires to be crammed, or to cram himself, with ready-digested knowledge. There can be no excuse for a student of Plant-life who neglects to carry out the simple observations and experiments for which directions are given in this book. In most cases, the necessary materials and apparatus can easily be obtained at a cost so trifling as to place them within the reach of all.

I hope that this book will be helpful to all who are interested in Plant-life, as well as to students preparing for such examinations as those of the Board of Education, Oxford and Cambridge Locals, London University Matriculation. It is intended merely as an introduction to Botany, but I am convinced that the student who works faithfully through it, and carries out all the observations and experiments, will, if imbued with the spirit of inquiry and research, have laid a solid foundation for a sound acquaintance with the structure and life-processes of plants, the relations of plants to their surroundings, and the evolu-

tion and classification of the Angiospermous flowering-plants. I have not included much microscopic work, but in the classes referred to we have found that simple work on the microscopic structure of roots, stems, leaves, pollen-tubes, etc., has proved a useful sequel to naked-eye and lens work. The provision of a compound microscope for each student would be, of course, neither practicable nor advisable in large classes of young students, but, though much good work in Plant Biology can be done without one, every teacher and serious student of this subject should get a cheap instrument, costing about £5, which will answer quite well (see Appendix IV.).

The following list includes books which contain useful suggestions for observations and experiments, and which may on that account be recommended to teachers and others interested in Plant-life for use after they have worked through the present book :

Ganong : *The Teaching Botanist* (Macmillan).

*Hennessy : *The School Garden* (Blackie).

Miall : *Round the Year* (Macmillan).

Miall : *House, Field, and Garden* (Arnold).

Osterhout : *Experiments with Plants* (Macmillan).

Scott Elliott : *Nature Studies* (Blackie).

Many books on "Plant-life" and "Nature Study" have been published, but they are mostly of the nature of "crutches," and they are quite unnecessary to the student who works through a course such as is provided in this

* A series of very cheap but useful booklets on gardening is published by Toogood & Son, Southampton, who will send a list on application.

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PLANT BIOLOGY.

CHAPTER I.

THE BROAD BEAN PLANT.

1. **Our Type.** Probably the best introduction to the study of Plant-life is afforded by the thorough examination of some common and easily obtained plant. The Broad Bean or Windsor Bean (*Vicia faba*), which we shall study in some detail as a type of flowering plants, is distinguished from other "bean-plants" (*e.g.* French or Kidney Bean, Scarlet Runner) by its erect mode of growth, its square stem, its leaves with large stipules and usually four or five oval leaflets, its white flowers with a black blotch on each lateral petal ("wing-petal"). It is commonly cultivated for its large edible seeds, and (like most cultivated plants) shows several varieties, differing in such details as shape and size of pod and seed and in times of flowering. One variety is the Field or Horse Bean, of which the seeds are used chiefly for feeding horses, the "straw" for stabling purposes; its seeds are much smaller and less flattened than those of the typical Windsor Broad Bean. The Broad Bean has been cultivated from very early times (probably before 1000 B.C.), and was introduced into Britain by the Romans. The Roman family of the Fabii are said to have derived their name from success in cultivating beans; the advice of Pythagoras to his disciples, to abstain from beans, is probably an allusion to the fact that beans were used in the Athenian ballot. There is some uncertainty about the original native home of the Broad Bean, before it was brought into cultivation, but it appears to have spread from two

centres, one in Persia, the other in North Africa; it probably never grew wild in Europe.

Exp. 1. *Materials for Study.* Dig up an entire Broad Bean plant in the garden (or the very similar Horse Bean grown in fields), and free the root from the soil that clings to it by shaking it to and fro in a pailful of water and afterwards washing under a stream of water from a tap. Set the plant in a basin of clean water, so as to allow the branching root to spread out, as well as to prevent its drying up.

If complete flowering and fruiting plants cannot be obtained at once, begin by studying the seed and its germination (Art. 9 and rest of this chapter; Ch. II.). Make successive sowings in the garden, also in pots and boxes, so as to get abundant material, in the form of seedlings, to start work with.

Exp. 2. *Hints on Lens Work.* So much can be done with a lens, especially if a microscope is not available, that some hints on lens work may be useful. The best kind of lens is the "aplanatic" or "platyscopic," which gives a flat field of vision without distortion of the edges; but a triple folding-lens will do, and is much cheaper. It is easy to make a simple stand to carry the lens, and to allow of both hands being used in dissecting the specimen examined. The lens can be fixed to a cork which slides up and down a vertical rod, *e.g.* a knitting-needle or hat-pin, inserted into a wooden base. Another plan, much simpler, is to use a watchmaker's lens, worn in the same way as a monocle. Another useful plan is to get a piece of thick glass, about 9 by 4 in., to one side of it paste two pieces of thick paper, each 3 by 4 in., one black, the other white (or a single piece, 6 by 4 in., with one half painted black). Keep the papered side downwards, placing on the upper side the objects to be examined with the lens; move them along so as to see their appearance against the opaque white and black surfaces, and also against the light through the transparent part of the plate.

2. **The Root** consists of a main downward-growing axis (continuous with the upward-growing axis or stem), from which arise branches that spread out from it. Are these first branches horizontal or not? Do they all make the same angle with the main root? These first branches give rise in their turn to finer branches; in what directions do *these* grow in the soil, and how many times may the process of branching be repeated? *Compare the different directions* of growth taken by the main axis and by the successive sets of branches. How do these differences help the root to come into contact with as much soil-space as possible in the most economical way?

Exp. 3. *Branching of Root.* Are the first branches scattered over the surface of the main root? To make out their arrangement, cut out a straight piece of main root, about 6 in. long, cut off the branches about an inch from their origin, and look along the piece from end to end. Sketch the piece, showing the rows of branches arranged along the axis. How many rows are there? Does the arrangement in longitudinal rows extend to the further branchings of the root?

Exp. 4. *Origin of Rootlets.* Examine closely the place where a branch (rootlet) leaves the parent-root. Is the surface smooth and continuous, or is there anything visible that suggests the way in which the branch arose from the parent-root? What further information is gained by cutting across the parent-root at this point, with a sharp knife or a razor, and examining with a lens the cut surface? In what region of the main root are the branches shortest and thinnest? Look for young branches just emerging from the parent-root; in what direction do they grow at first? See fig. 1.

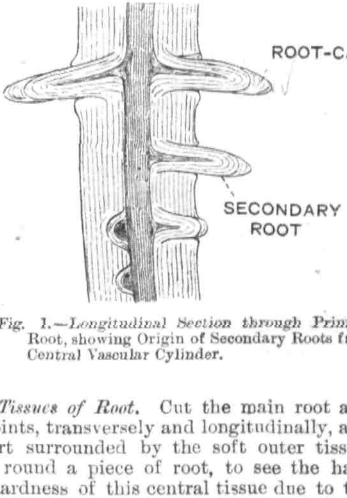

Fig. 1.—Longitudinal Section through Primary Root, showing Origin of Secondary Roots from Central Vascular Cylinder.

Exp. 5. *Hard and Soft Tissues of Root.* Cut the main root and the branches at several points, transversely and longitudinally, and note the hard central part surrounded by the soft outer tissue. Scrape the latter off, all round a piece of root, to see the hard central cylinder. Is the hardness of this central tissue due to the presence of woody substance, as in old roots as well as stems of trees? It is easy to find out. Get some aniline chloride (about $1\frac{1}{2}d.$ per ounce), dissolve in a little alcohol, and add water to make a 10 per cent. solution. Dip a wooden match into the solution; does the match turn bright yellow when withdrawn? If the colour does not appear quickly, add a few drops of hydrochloric acid to the solution. This solution affords a ready test for woody substance (*lignin*). Place some on your sections of the root, and notice which parts turn yellow.

Exp. 6. *Root-Tip.* Note the gradual tapering of the axis and of the rootlets towards their free ends, and the softness and whiteness of the latter as compared with the older parts. Cut off the

ends of some of the rootlets, about an inch behind the extreme tip, place them in a drop of water on a glass slide, and examine them with the lens; try holding the slide (1) against the light, (2) over a white surface, (3) over a black surface.

Exp. 7. *Root-Hairs.* Look for very fine threads, which will be found behind the root-tip, if the latter has not been damaged. These are the root-hairs, to which small particles of soil may still be sticking. Root-hairs are more easily seen in seedlings (Ch. II., III.). They previously existed on the older parts of the root, but they disappear as the root grows, while new hairs are continually being formed just behind the growing extremity of each rootlet. See fig. 46.

Exp. 8. *Root-Cap.* At the end of each rootlet, note the more transparent conical mass at the extreme tip, separated from the denser main body of the rootlet by a curved outline. This conical mass is the root-cap; it is thickest at the tip and extends a little distance at the sides, fitting over the end of the rootlet like a thimble on a finger.

Root-hairs and root-cap can be more easily examined in a seedling; these structures are often damaged in removing the mature plant from the soil.

Exp. 9. *Root-Nodules.* Note, here and there on the main root and the rootlets, little wart-like swellings, varying in size and shape. These swellings (nodules or tubercles) are characteristic of the roots of beans, peas, clover, and allied plants.

Further work on the root is given in Ch. III.

3. **The Shoot.** The whole of the upper part of the bean-plant, above the ground, may be called the *shoot*, as distinguished from the root, which grows in the soil.* In passing from the downward-growing axis or root to the upward-growing axis or stem, what changes do you notice in (*a*) shape of axis, (*b*) colour of axis, (*c*) nature of appendages carried by the axis? Note the four flat sides of the stem, and its green colour, often tinged with red. We saw that the root consists of a main cylindrical axis which is covered at the tip by a root-cap and which bears as appendages (*a*) root-hairs, (*b*) root-tubercles, (*c*) rootlets which repeat the form of the main axis and bear the same appendages. What are the appendages of the shoot-axis (stem)? (*a*) Some of these consist of a stalk which is grooved on its

* We shall see later that it is not always easy to distinguish at once between the root and the shoot of a plant. Nearly all the characters generally used to define these parts break down in certain exceptional cases.

upper surface, carries a number of thin flat outgrowths on either side, and (usually) ends in a slender prolongation. (*b*) Other appendages of the stem consist of a four-sided stalk which carries appendages like (*a*), and which therefore repeats the form of the main stem itself and may be called a *branch* of the stem, just as a rootlet is a branch of the root. In many plants, *e.g.* Wallflower, the first kind of stem appendage consists of an undivided thin flat piece; such an appendage is called a *simple leaf*. The corresponding appendage of the Bean is also a leaf, but here the leaf is not simple, as in the Wallflower, but *compound*, its thin flat portion being divided into several pieces, the *leaflets*.

Exp. 10. *Hard and Soft Tissues of Stem.* Cut slices across the stem at several places, starting with the uppermost (youngest) parts and working downwards. Arrange the slices in order on your glass plate, cover with a little water, and examine with the lens. Note that the young parts are solid and soft, while the older parts are hollow and hard. Note the hard tissue lying within the soft green outer tissue. In young parts the hard tissue consists of separate strings (bundles) forming a ring of whitish points in cross-section; note the extra bundles lying outside of the ring, occupying two of the four projecting corners (there is a small bundle in each of the corners alternating with these two, but they are harder to see). In older parts the bundles are joined in a continuous hollow cylinder or tube (a complete ring in cross-section), but the extra bundles lie outside of this in the same positions as in the young parts. Now run the water off and place on the sections a little aniline chloride, noting the result. Cut the stem longitudinally into strips and note the bundles, which will be easier to follow if the strips are placed in potash solution for a short time. Scrape the soft outer tissue from a piece of stem and notice the hardness of the bundles, especially in the older parts.

Exp. 11. *Air-Spaces in Shoot.* You have noticed a central cavity in some of the cross-sections. How far does this cavity extend in the stem, and is it continuous? Find out by slitting up the whole stem from top to bottom. Does it run out into the branches and the leaves? What does it contain in the uninjured living stem? Lay a whole plant in a basin, cover it with cold water, and cut across the stem and the branches at several places; what do you notice escaping from the cut ends? Is this central cavity the only part that contains air? Take the plant out, replace the cold water by hot water (just boiled), and notice what happens when you place in it (*a*) a piece of stem only, with the cut ends previously well plugged with plasticine, (*b*) a whole plant. The results of these simple experiments show that

the whole shoot contains air-spaces and that these communicate with the atmosphere by openings scattered over the surface. From the number of bubbles seen to escape, the leaves evidently have more air-openings than the stem. Which side of a leaflet, upper or lower, seems to have most openings? These air-openings are called *stomates.*

4. **The Leaf.** Each leaf consists of an axis (leaf-stalk) which bears right and left a number of thin flat outgrowths.

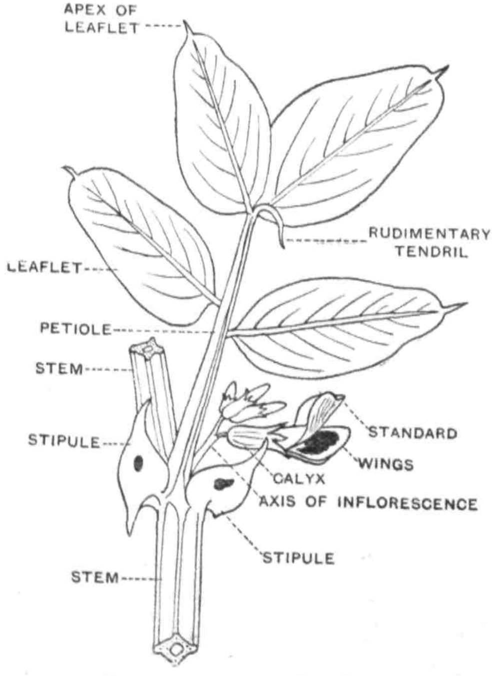

Fig. 2.—Part of a Broad Bean Plant.

The two lowest of these lie on each side at the base of the leaf-stalk, close to the stem; they are called *stipules,* to distinguish them from the leaflets carried higher up on the

stalk. The leaflets are rather variable in number, but we usually find a pair close together, right and left, near the top of the stalk, and from two to four spaced out on the stalk below these. Note the difference in shape between the leaflets (oval) and the stipules (triangular, like one lateral half of a spear-head); what other differences do they show? Notice the slender outgrowth into which the leaf-stalk is (usually) prolonged above the leaflets (fig. 2). Do any of the leaves in your plants bear a leaflet in place of this outgrowth, and do you find any leaves ending in structures intermediate between these two extremes? Note that the leaf-stalk comes off at one of the ridges of the stem, the stipules being against the two adjacent flat sides of the stem.

Exp. 12. *Arrangement of Leaves.* Follow the ridges along the stem, and find out in how many rows the leaves are arranged. Do leaves come off at all four ridges? Do the ridges run straight up and down the stem, or is there any twisting? Compare the leaf-arrangement in the Broad Bean with that observed in other plants which have square stems—*e.g.* White or Red Dead-nettle, Mint, Figwort, Coleus—and note any differences.

Exp. 13. *The Leaflet.* Notice the chief vein (midrib), which runs through the leaflet from the base to the tip. What do you notice at the extreme tip? Does the midrib divide the leaflet into exactly similar halves, or not? Which half is the larger in area, that towards the stem or that towards the free end of the whole leaf? Do you know of any other plants which have "lop-sided" leaflets, or leaves, like this (examine the leaves of Lime-tree, Elm, and other plants)? Note the branch-veins arising on either side from the midrib, the finer veins arising from these, and the delicate net-like arrangement of the still finer veins (hold the leaflet against the light). What differences do you notice between the upper and lower surfaces of the leaflet? Notice that the chief veins appear as grooves on one surface (which?) and as projections on the other.

Hold the leaflet, with the lower surface towards you, between the thumb and fore-finger of each hand, and, starting from a point on one edge, tear the leaflet across. Notice the thin colourless skin which can be torn off in this way, and the green inner tissue which is exposed; small specks of the green tissue remain attached to the skin, unless the tearing is done very carefully (try it several times, starting at different points on the edge of the leaflet). Now try to tear off the upper skin in the same way, and notice that it also is colourless, though a good deal of the green tissue always comes away with it. The leaflet therefore consists of a thin colourless skin (*epidermis*) covering its upper and lower surfaces, and a thick

middle green tissue which is denser towards the upper surface and looser towards the lower surface (how is this inferred from your tearing experiments?) and which contains the veins.

Dip a leaflet into water and notice, on lifting it out, that the water runs off the surface very quickly, leaving it dry. Lay a leaflet on the table and place a drop of water on either surface in turn; notice in both cases that the water forms a globule instead of spreading over the surface. This shows that the leaf is not easily wetted by water, and suggests that the surface is covered by some substance like wax. This waxy substance is similar to that which forms the "bloom" on Grapes, Plums, etc., so that one might say the Broad Bean leaflet is covered with "bloom," which prevents water from wetting it and reaching the inner tissue. Try to remove the bloom by rubbing the leaflet gently (1) with a dry cloth, (2) with a cloth dipped into warm water; water placed on the leaflet will then wet the surface and spread over it.

Exp. 14. *The Stipules.* How does a stipule differ from a leaflet in shape, colour, and texture? Has it any veins (hold it against the light)? Notice the patch near the centre of the stipule; at first it is bright red or violet in colour, later it becomes brown or black. On which surface of the stipule is this patch most easily seen? This patch consists of minute glandular hairs,* very closely crowded together on the lower surface of the stipule. A similar patch of glands occurs on the stipule in the Common Vetch of fields (*Vicia sativa*), the nearest ally of the Broad Bean among British plants. Its functions are doubtful; possibly it helps in attracting insects to the flowers, or in feeding small insects (*e.g.* plant-lice) and thus keeping them away from the flowers.

Exp. 15. *The Leaf-Stalk* (*Petiole*). Note the groove on the upper surface, making the leaf-stalk gutter-shaped. What does this comparison with a gutter suggest as to the use of the groove in wet weather? Test the matter by a simple experiment with a watering-pot, or watch a plant during a shower of rain. Does this suggest also the use of the little pointed tip at the end of each leaflet? What about the narrow prolonged tip at the end of the leaf-stalk? The nearest relatives of the Broad Bean are the Vetches and Peas, which differ from our type in being weak-stemmed climbing plants. Get any of these and compare their leaves with that of the Broad Bean. What light does the comparison throw on the nature of this part of the Broad Bean leaf? A special organ used for climbing is called a *tendril* (see Art. 217). Make out with the lens the structure of the leaf-stalk. How are the bundles arranged? Is there a central air-channel, and is it continuous with the air-channel of the stem, or the branch, that bears the leaf? Examine the structure of the leaf-stalk by the same methods as in the case of the stem. That of the leaflet will be dealt with later (Ch. III.).

* See Art. 222, Ch. V.

5. **The "Skeleton" of the Plant.** We have now learned something about the inner structure of the plant; to learn much more about it we should need a microscope. The most obvious difference in the inner structure of root and stem is the different position of the hard parts, which we might compare with the skeleton of an animal, since these hard parts support the plant and help it to keep firm. The plant's skeleton has other important uses, which will be dealt with later. Meanwhile we may consider its use in strengthening the plant. Why are the hard tissues of the stem arranged in a hollow cylinder, or tube, like the pillars that support the galleries in buildings? Why are they packed together towards the centre in the case of the root, forming a tough central cord? Why are the chief bundles in the leaf-stalk arranged like the letter U in a cross-section? Why are the chief veins (bundles) of the leaflet arranged like a feather, and why do they project on the lower side of the leaflet? Why are the finer leaflet-veins arranged in a network? Most of these questions can be answered by considering the results of simple experiments on the bending of a beam of wood (or other material) fixed to a wall by one end and loaded at the other. The lowering of the loaded free end is (*a*) proportional to the load, (*b*) proportional to the cube of the length of the beam, (*c*) inversely proportional to the breadth of the beam, (*d*) inversely proportional to the cube of the depth of the beam. From (*c*) and (*d*) we see at once why it is so much more advantageous to increase the depth than to increase the breadth of a beam. For when the beam is bending, the upper side lengthens and the lower side shortens, but the middle portion of the beam neither lengthens nor shortens. Exactly the same applies when the beam is set upright instead of horizontally, and force is applied to it from one side. Hence it is a good plan to put the hard material near the outside, and this is done in the hollow pillar and the girder. In this way the strength of the structure is, using the same amount of material, greatly increased. Do you see how these facts apply to the bean-plant, and how the plant successfully meets the mechanical needs of the various parts, and at the same

time the need for economy in the amount of material used to make these parts strong enough? The leaflets have to be supported and spread out to air and light; the stem has to carry the leaves and branches and has also to resist undue bending before the wind. The root, on the other hand, being embedded in the soil, has no weight to support, but it has to keep a firm hold of the soil (the root-hairs help greatly in this), and it must be able to resist pulling or tugging strains. Hence the best arrangement for the root is to have the hard tissue at the centre, forming a compact cord.

6. **Branches and Buds.** You will have noticed that each branch of the stem arises just above the base of a leaf, and that as a rule they become shorter towards the upper end of the stem. Pull off the young leaves at the end of the stem or of a branch, to see the small young branches (*buds*), one above the base of each leaf. These buds are called *axillary*, the space between the leaf-base and the part of the stem above it being called the *axil* of the leaf. At the very end of the main stem and of each branch there is a *terminal bud.* A bud is simply a young shoot, consisting of a short axis (stem) bearing young leaves which are closely crowded together and overlap the growing apex of the axis. Later on, the stem part of the bud grows in length and the leaves become spaced out on it, as well as growing larger.

The points on the stem where leaves come off are called *nodes*, the parts between the nodes being called *internodes*; but these names, though useful in describing plants, are often associated with a false conception of the shoot as being made up of "joints," each consisting of an internode and a node bearing one or more leaves. The node is merely the place where a leaf stands on the stem, and where the bundles of the stem divide and join with those of the leaf and also with each other; this often produces a swelling, *e.g.* in Grasses and the Pink family.

7. **The Flowers** of the Broad Bean are arranged in small clusters, each cluster arising in the axil of a leaf, and each flower is attached by a short stalk to the axis of the cluster, which occupies the same position on the shoot as

an ordinary branch. The cluster or flower-bearing branch is called an inflorescence. Turn down or pull off the leaf just below an *inflorescence*, and examine the latter closely. This special kind of inflorescence, with the individual flowers stalked and spaced out on the axis, is called a *raceme*; the youngest flowers are nearest the top.*

Note the parts of a single flower (fig. 3), starting from the outside:

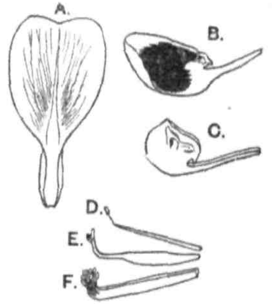

Fig. 3.—Dissection of Broad Bean Flower.

A, standard petal (front view); B, a wing petal (inner side); C, keel; D, free uppermost stamen; E, pistil; F, stamen-trough.

Exp. 16.† *The Calyx*, a greenish or colourless cup, with its free edge produced into five pointed lobes. Note the veins which start from the bottom of the cup, one running up the middle of each lobe, others between the lobes.

Exp. 17. *The Corolla*, consisting apparently of four pieces, a large upper piece (*standard*), two smaller side pieces (*wings*), and a lower boat-shaped piece (*keel*). Note the way in which the standard is folded below over the wings, which in turn enfold the keel. The standard is on the upper (posterior) side of the flower, *i.e.* the side towards the axis of the inflorescence; note the position of each of the calyx-lobes with reference to the axis, the odd one being the lowest. Open the calyx by cutting or tearing it between the two upper lobes, to see the exact shape and position of each of the four parts of the corolla. Remove the standard and sketch it (front surface and side view); note its broad upper part, marked by coloured streaks, and the narrow lower part by which it is attached to the *receptacle* (*i.e.* the expanded upper end of the flower-stalk, to which all the parts of the flowers are attached). In each wing note the narrow stalk, and the broad oval portion which has a large blackish spot. Gently pull each wing outwards, and note that it clings to the outer surface of the keel; can it be pulled off without tearing anything? Note the way in which the wing on each side is locked with the keel; at this place the wing and the keel show a series of folds, the corrugated surfaces fitting together.

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* See Art. 258, Ch. VI.

† In dissecting flowers, use a sharp pen-knife (a pair of fine scissors will also be useful), a pair of forceps for seizing the parts of the flower, and a lens.

Remove and sketch one of the wings, both from inner side and outer side. In removing the standard and the wings, note that these pieces (*petals*) alternate in position with the calyx-lobes, *i.e.* the insertion of each of these three petals is just inside the space between two of the calyx-lobes. Now examine the keel, and note that it is carried on two separate stalks; detach these at their bases and pull them apart, when the keel will split along its sharp lower edge into two pieces. The corolla, then, consists in reality of five petals; the two lowest being attached to each other to form the keel, and the five petals alternate in position with the five *sepals* (calyx-lobes).

Exp. 18. *The Stamens* (fig. 4). On opening up the keel, you will see a number of small oval bodies (*anthers*), each carried at the end of a thin stalk (*filament*). How many anthers are there? If you see any stalks bare at the end, try another flower (a young unopened flower is best). Trace the stalks down, and notice that

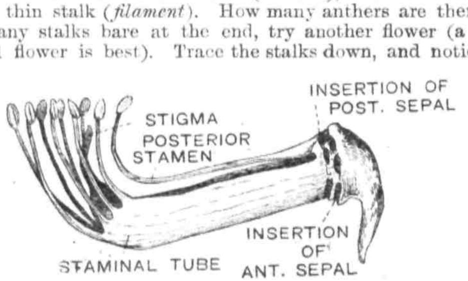

Fig. 4.—Stamens and Pistil of Pea Flower.

most of them are joined below to a thin colourless plate which is folded longitudinally. Does this folded plate form a complete tube or is it open? Where is the opening, and how is it covered over? Are any of the filaments free from the folded plate? Each anther, with its filament, constitutes a *stamen*, but only the uppermost stamen is free right down to the flower-axis; the others arise from the "stamen-trough." The upper parts of all the stamens bend sharply upwards, to suit the shape of the keel, in which they are enclosed; there is a narrow opening along the upper side of the keel, above the free stamen. Examine an anther with the lens, noting the two lobes divided by a longitudinal groove, and each showing a less marked groove; the anther consists of four *pollen-sacs* lying side by side. This can only be seen in a young flower; in an older one the anther will have opened by two slits, one at each side, allowing the yellow dust-like *pollen* to escape. Sketch the ten stamens, with the "stamen-trough" as seen from the side; then cut round the base of the trough, remove it, and sketch it spread out.

Exp. 19. *The Pistil*, the innermost part of the flower, is now seen. It consists of a long green lower part with flattened sides, and a

tapering free end produced into a slender outgrowth (*style*), which bends upwards and bears a tuft of hairs on the lower side of the bend, just below the tip. Examine these parts carefully, and sketch the whole pistil in side view. The lower part of the pistil resembles a small bean-pod, and for the present we may call it the "young pod." Is it hollow, and does it contain anything answering to the seeds found in the bean-pod? Cut it across, and open it up, to see what we may at present call the "young seeds." To which side (upper or lower) of the cavity are they attached?

Make and sketch a longitudinal section of the entire flower corresponding to that shown in fig. 82.

8. **The Fruit** (fig. 5). Watch some flowers from day to day, or compare different flowers on the same plant, and note any changes that occur as they grow older. What becomes of the calyx, corolla, stamens, style, young pod? What parts of the flower (*a*) wither, (*b*) persist, (*c*) grow larger? Watch the growth of the fruit (pod), opening up pods of different ages, to see what changes have occurred. How does the pod change in texture and in colour as it grows older and larger? How does the ripe pod open to let the ripe seeds out?

Fig. 5.—The Developing Pods of the Bean.

Do any changes occur in the rest of the plant (leaves, etc.) while the pods are ripening? What happens if you leave the plant undisturbed in the ground after the pods have ripened? What parts of the fruiting bean-plant remain alive during the winter? What will next year's plants be produced from?

9. **The Seed.** Examine some ripe pods containing seeds, also get a supply of dry seeds (Windsor Broad Bean, about 6*d*. per quart). Notice the black (or brown) mark on the thicker end of the seed (fig. 6 A). How was this mark on the loose seed produced? How does the seed become loose, and what does it break from when the pod opens? This mark may be called the *scar* of the *seed-stalk*. The dry seeds have a shrunken appearance, while fresh seeds are smooth and rounded. In what other respects do dry seeds differ from fresh seeds?

Exp. 20. Take twenty seeds of each kind (dry and fresh), as nearly equal in size as possible; weigh the two lots, and note the

difference. Put the dry seeds into water, and notice that in a few days they have swelled and become smooth and rounded, like the fresh seeds.

Exp. 21. Examine from time to time some dry seeds which have been placed in water, and notice that at first the surface becomes thrown into folds. Cut across the seed, and note that these folds are produced by a *coat* which encloses the contents of the seed. Evidently the coat at first absorbs water and swells more rapidly than the contents; this loosens the coat and makes it much easier to remove in a seed that has been soaked in water for a day or two.

Exp. 22. How does the water enter the seed? Is there any opening in the coat? Do you recall how we found out that various parts of the bean-plant contained air, which communicates with the atmosphere by openings on the surface of stem and leaves? Drop some dry seeds into water that has just been boiled, and notice the stream of bubbles given off. Where do the air-bubbles escape? Wipe this end of the seed dry, in some seeds that have soaked for a few days, and look for the opening; squeeze the seed and see whether water oozes out. This opening is the *micropyle* (Greek, "little gate"). Is there a coat over the very young seed, and if so, has it an opening too? Examine seeds from pods of different ages, starting with fairly large ones, and working back until the seeds are too small to allow of these points being clearly made out.

Exp. 23. Remove the coat from a soaked seed, starting at the end opposite the scar. Note the two large whitish ***seed-lobes*** or ***cotyledons***, whose flat or slightly concave inner sides are pressed against each other. When you have stripped off the upper half of the coat, pull off the rest of it (the part covering the scar end) entire, like a cup. Note the smooth tapering body projecting from between the cotyledons and pointing towards that end of the scar where the micropyle is; also note the little pocket on the inner surface of the seed-coat, into which the projecting body fits (fig. 6 B).

Exp. 24. *Radicle and Plumule.* Now pull apart the seed-lobes, and remove one by breaking across the short stalk by which it is joined to the thickest part of the projecting body. This brings to view a curved body lying between the seed-lobes, fitting into a groove on the flat inner surface of each lobe, and forming a continuous line with the projecting body. Has it, like the latter, an even surface, or does it bear any outgrowths? Examine it carefully with the lens, and try to turn back the outgrowths with a pin, without tearing them, so as to make out the positions of the outer ones. The projecting conical outgrowth resembles a root, and a longitudinal section through its tapering end shows a root-cap at the tip. It is usually called the *radicle*, though, strictly speaking, only the free end has the characters of a root. The curved body is a bud; it is called the *plumule*, from its feather-like appearance in plants belonging to the same family as our type (fig. 6 B).

Exp. 25. Fill a wooden box, at least a foot deep, with moist sawdust, bog moss, or soil, and plant seeds about half an inch below the surface. See Ch. II. for details of germination. In the young green shoot that comes above the soil, notice the forms of the earliest leaves.

10. **The Seedling** (fig. 6 c). The first leaf above ground consists of a single piece with its margin cut by shallow notches into three lobes; the second leaf is divided deeply into three lobes, the middle lobe long and narrow, the lateral lobes broad and triangular. Then come several

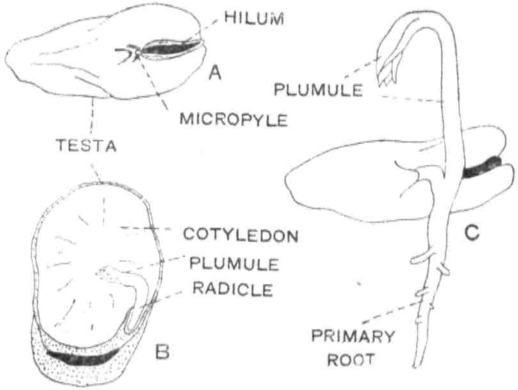

Fig. 6.—Seed and Embryo of Broad Bean.
A, entire; B, one cotyledon removed; C, after germination.

leaves, each consisting of two stipules and a short stalk which bears a pair of oval leaflets (note their folded appearance at first) and is prolonged into a rudimentary tendril. After several leaves like this we get leaves of the mature type, in which the stalk is lengthened below the terminal pair of leaflets, and carries two, three, or four additional leaflets. Have these early leaves, like the later ones, buds in their axils? In the first two leaves that appear on the young stem, the three lobes evidently represent the two stipules and the rudimentary tendril (or the end leaflet which sometimes replaces it).

Carefully pull up a seedling without injuring the root, and compare the latter with the root of the mature plant. Trace the young root upwards and the young shoot downwards, and notice the torn seed-coat and the cotyledons. In the axil of each cotyledon there is usually a bud. The cotyledons are therefore leaves, though differing from ordinary leaves (foliage-leaves) in many respects.

11. **Seedling compared with Seed.** The young plant, or seedling, has evidently grown from the whole of the seed-contents (*i.e.* everything inside the seed-coat), for we have seen that even the cotyledons are leaves, having buds in their axils. The cotyledons are the first leaves of the young plant, which is called the *embryo* while still inside the seed. The embryo consists of an axis which bears the two cotyledons at about the middle, and which ends in a root (covered by a root-cap) at one extremity and a bud (bearing young foliage-leaves) at the other.

12. **Seedling compared with Mature Plant.** We have noted the simple form of the earliest leaves as compared with the older ones. The cotyledons are opposite each other and are attached to the same point (node) on the axis, but the early foliage-leaves show the same arrangement (alternate, in two opposite rows) as in the mature plant. The two lowest leaves cover and protect the younger and more highly developed leaves which lie within them in the plumule. The root of the seedling shows the same general appearance and structure as that of the mature plant, into which it grows, later on forming the characteristic nodules.

QUESTIONS ON CHAPTER I.

1. For what purposes is the Broad Bean grown (*a*) by the market-gardener, or in kitchen-gardens, (*b*) by the farmer in his fields?

2. At what times of year is the Broad Bean commonly sown, and during what months may it be seen (*a*) in flower, (*b*) with ripe fruits?

3. How are the lateral roots arranged on the main root in the Broad Bean, and in what directions do they grow?

4. Write down in two parallel columns the contrasted characters of Root and Shoot, as to direction of growth, colour, shape of main axis and branches, appendages carried on axis, etc.

5. Describe the naked-eye features of the main axis (stem), the branches, and the leaves. How are the leaves arranged, and how are they related to the branches?

6. Describe the internal structure of the stem, as seen in sections examined with a lens.

7. Describe the general appearance of a leaf of Broad Bean. Sketch a single leaf, with the part of the stem or branch from which it springs.

8. Describe the arrangement of the hard tissue of root, stem, leaf-stalk, and leaflet. Try to account for the differences you describe.

9. Describe exectly what happens when you pour water on the leaves of a Broad Bean plant.

10. Describe the leaves of any other plants belonging to the Bean family which you have examined, and compare them with those of the Broad Bean, noting the points of resemblance and difference.

11. Describe the naked-eye appearance of the various parts of the Broad Bean flower, with sketches.

12. Describe, from your own observations, what insects may be seen on the Broad Bean plant or visiting its flowers. Which of these insects do you suppose are injurious, and which useful, to the plant?

13. Describe, from your own observations, the changes that occur in the flower from the time it opens until the fruit (pod) is ripe.

14. How does the pod open if allowed to remain on the plant until it is quite ripe, and what do you find inside it?

15. Describe the external features of a Broad Bean seed, with sketches.

16. Describe the parts seen after removing the seed-coat, with sketches.

17. Describe what happens when a dry Bean seed is placed in water, and what you see after planting the soaked seed in soil or sawdust.

18. Describe a young plant (seedling) of Broad Bean, and compare its parts with those seen in the seed.

19. How do the earliest leaves of the seedling differ from those of the mature Broad Bean plant?

CHAPTER II.

SEEDS AND SEEDLINGS.

13. **Balances and Weights.** For various experiments with plants you will need (1) a rough balance for large weights, and (2) a finer balance for smaller weights. For the first, cooking-scales with weights from 7 lb. to ¼ oz., or a cheap spring-balance, will suffice. If you have not a small balance, get a cheap pair of apothecaries' scales (about 4*s.*) and suspend them from a ˥-shaped wooden frame fixed to a board below. If you get a single gram-weight and the fractions, you can make duplicate gram-weights from sheet-lead. The **metric system** of weights should be used. The unit of length in this system is the metre, a platinum rod kept in Paris and originally supposed to be a ten-millionth part of the distance from the North Pole to the Equator. The metre is multiplied and divided by 10 for the higher and lower measures of length; the Greek prefixes *deca-*, *hecto-*, and *kilo-* represent 10, 100, and 1000, and the Latin prefixes *deci-*, *centi-*, and *milli-* represent ·1, ·01, and ·001. The same prefixes are used in the other measures. The unit of volume is the cubic decimetre, or **litre**, but the cubic centimetre (*i.e.* the millilitre), usually written "c.c.," is often used for volumes less than a litre (1000 c.c.). The weight of 1 c.c. of distilled water at 4° C. is the unit of weight, the **gram**, with multiples and subdivisions as before.

Place an inch-rule graduated to tenths or eighths and a centimetre-rule graduated to millimetres edge to edge, and find how many centimetres are equal to a foot. If the scales are accurate, you should get the number 30·5.

Metric Equivalents (Approximate).

1 inch = 2·5 centimetres.	1 centimetre = ⅖ inch.
1 ounce (avoir.) = 28 grams.	1 gram = 15 grains.
1 fluid ounce = 28 c.c.	100 c.c. = 3½ fluid ounces.

14. **Thermometers.** An instrument for measuring temperature is called a thermometer, and the one in most general use is the Mercury Thermometer. This consists of a glass bulb containing mercury, and a tube of very fine bore which is joined to the bulb and sealed off at the top. All liquids expand when heated (as also do ordinary solids and gases), so that a rise of temperature causes the mercury to expand in the bulb and hence to rise in the capillary tube. The

narrower the bore of the tube, the greater will be the rise of the mercury in it, and in this way the expansion of the mercury, which is really very slight in amount, is made readily visible. If the bulb is placed in melting ice the point to which the mercury sinks in the tube is marked freezing-point, 0° Centigrade or 32° Fahrenheit. On placing the instrument in steam at atmospheric pressure, the boiling-point of water is indicated, and is marked 100° Centigrade or 212° Fahrenheit. The tube is marked off into degrees between these two points, the freezing- and boiling-point of water. On the Centigrade scale there will be 100 divisions between the two, and on the Fahrenheit scale 180.

Mercury freezes at −39° C. and boils at 357° C., so that it cannot be used for temperatures above and below these limits. The freezing-point of alcohol is lower than that of mercury, and hence it can be used for still lower temperatures; but since alcohol boils at 78° C. it cannot be used for temperatures at all approaching that of boiling water.

15. **Hints on fitting up Apparatus.** As you will be constantly called upon during the course to accurately fit flasks, etc., with corks bored with one or more holes, and bend glass tubing to various angles, you had better master these simple operations at once.

(*a*) **Fit a flask of medium size with a cork.** Select a cork a little too large; wrap it in a piece of paper, and using gentle pressure with your foot, roll it to and fro upon the ground. This softens the cork, and the risk of breaking the neck of the flask is lessened. If still too large, file down the cork equally all round.

(*b*) **Bore a cork lengthwise and fit a glass tube tightly into the hole made.** Select a cork-borer (fig. 8) slightly less in diameter

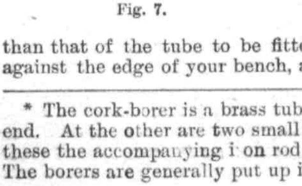

Fig. 7.

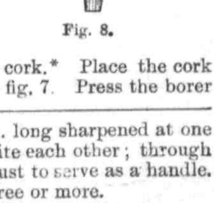

Fig. 8.

than that of the tube to be fitted into the cork.* Place the cork against the edge of your bench, as shown in fig. 7. Press the borer

* The cork-borer is a brass tube about 5 in. long sharpened at one end. At the other are two small holes opposite each other; through these the accompanying iron rod may be thrust to serve as a handle. The borers are generally put up in sets of three or more.

Exp. 27. *Glass-sided Germination Boxes.* Get two oblong wooden boxes (depth should be at least a foot for the long roots of bean seedlings).

(*a*) Remove one of the longer sides and replace it by a vertical sheet of glass; at each end of the box fasten a strip of wood on each side of the glass, or simply knock tacks in to keep the glass side in position.

(*b*) Make a similar box, but fix the glass side so that it slopes downwards and inwards. Fill the boxes with moist sawdust, and place the seeds close to the glass side, most of them about an inch below the surface of the sawdust, but some lower down.

17. **Early Stages of Germination.** In your germination jars and boxes place (1) dry seeds, (2) seeds that have lain in water for two days. Which of these germinate the more rapidly, other things being equal? How do the young root and the young shoot emerge from the seed-coat? Which is the first to appear on the outside? Notice the V-shaped split in the coat along the edge of the radicle-pocket, caused by the radicle swelling up and raising the outer wall of the pocket as a triangular flap (does the apex of the triangle reach as far as the micropyle, or not?). Watch carefully the way in which the stalk of each cotyledon grows in length, pushing the cotyledons apart and allowing the curved plumule to grow out between them. For how long does the young root keep the lead as regards rate of growth in length? What is the advantage to the young plant in the fact that the young root emerges before, and keeps on growing faster than, the young shoot? What advantage in the hooked form of the young shoot? Watch carefully the growth of radicle and plumule in seeds that have been placed low down in jar or box, so as to be covered by about 6 in. of sawdust or soil. Plant seeds in different positions (with scar end downwards, upwards, at one side) and compare the growth of radicle and plumule in each case.

Make sketches, at least natural size, of (1) entire seed from scar end; (2) same from the front, *i.e.* thicker edge, showing the bulge caused by the radicle; (3) same in side view; (4) side view showing the triangular flap and the radicle growing out; (5) front view showing the same; (6) and (7) side and front views of embryo, after removing seed-coat; (8) same after removing one cotyledon, side

view; (9) lower (scar end) half of empty seed-coat, interior view showing pocket and ridge inside scar; (10) section through entire seed, to show pocket with radicle fitting into it (cut between cotyledons). Also sketch successive stages in germination of seeds planted in different positions and at different depths.

Exp. 28. Will a seed germinate if kept quite dry? Place some dry seeds in dry sawdust and others in moist sawdust (an inch below the surface); compare the results after a week or two.

Exp. 29. Are seeds able to absorb water from moist air? Can they absorb enough in this way to enable them to germinate? Fold up a piece of zinc gauze to form an open box and suspend it by threads from the lower side of a cork bung (or a wooden cover), so that it can hang down into a wide jar containing some water. Weigh some dry seeds, put them into a gauze box, do not let them come into contact with the water. Weigh the seeds again from day to day, to see whether they have absorbed water from the moist air in the jar. *Why do seeds sometimes germinate or become mouldy when kept in a damp cupboard?*

Exp. 30. Are the "dry" seeds sold by the seedsman quite dry, or do they contain any water at all? Into a dry test-tube (warm the tube all over to make sure it is quite dry) put a "dry" seed * and heat over a Bunsen or spirit-lamp, applying the flame to the bottom of the test-tube. Notice the drops of water which condense in the colder upper part of the tube. With a dry knife cut a dry seed into pieces and notice that the water is driven off more quickly than when a whole seed is heated; why? Cut 20 dry seeds into pieces; weigh these, and then dry them thoroughly without scorching or charring them at all. This is best done by placing the seeds for a few hours in an oven, or by means of a sand-bath or a water-bath (see fig. 12). Compare the weight of the thoroughly dried pieces and find out the percentage weight of water which the "dry" seeds originally contained (usually about 10 per cent.). This amount of water, though not sufficient to allow of germination taking place, is evidently necessary for the seed to remain alive and capable of germinating.

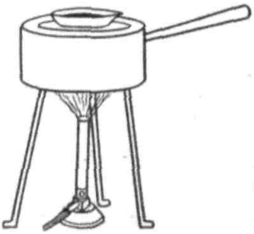

Fig. 12.—Water-bath.

* For many experiments where it is better to use small seeds, or where a large number is necessary, use such seeds as horse bean ("winter bean" of seedsmen), pea, wheat, barley.

18. **Simple Drying Apparatus.** To dry seeds, etc., without charring them, use a slow oven, a water-bath, or a sand-bath over a small flame. A simple water-bath consists of two tin cups and an iron tripod to rest them on; half fill one cup with water, and into it put the other cup containing the seeds to be dried. As an alternative, use a saucepan for the water and a saucer for the seeds to be dried. A simple sand-bath consists of a shallow tin or pan filled with sand, supported on a tripod and heated below as usual, the seeds being placed in a smaller tin or a saucer resting on the sand. Unless you have a good drying-oven, you will find the sand-bath just described very useful; the simple water-bath described has drawbacks, for the lower cup must be filled up as the water boils away, and the water-vapour given off may reach the seeds in the upper cup.

Exp. 31. Keep some "dry" seeds in a drying-oven or drying-bath until they show no further loss in weight, and then find out whether they swell up in water and whether they germinate. The results will show that killed seeds still have the property of absorbing water. What other dead substances have this property? By what methods, besides thorough drying, could you kill seeds? Try boiling them in water or steeping them for a few days in poisonous liquids—*e.g.* alcohol, acids, caustic potash.

19. **Water required for Germination.** Our experiments have shown that water is necessary for the germination of a seed to begin, that without water the young plant in the seed cannot awake to active life and growth. We shall see later that water is absolutely essential in all the active life-processes of plants. It is obvious, therefore, that we must study the properties of water, so far as they bear upon plant-life. The chemical composition of water does not concern us just at present, but some of its physical properties are of the utmost importance in connexion with germination. The following pages dealing with water should be referred to again and again, and as many as possible of the experiments made by the student.

20. As will be shown later (Ch. IV.), water consists of two elements,* hydrogen and oxygen, which are chemically united, forming a *compound*. This compound (water) differs entirely in its properties from hydrogen and oxygen, which are both gases (except at extremely low temperatures).

Water exists in the three states of ice, liquid water, and steam. It is never found in a state of purity in nature, since nearly all

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* An element is a substance which has never been separated into two or more different substances.

substances are more or less soluble in it. Even rain water contains gases dissolved from the atmosphere (oxygen, nitrogen, carbon dioxide, ammonia). Spring or river water contains various dissolved salts, which are carried into the sea by the rivers and there left behind, when the water evaporates to form clouds.

When water is boiled, the dissolved gases are driven out of solution, and if the water is entirely evaporated, the dissolved solids are left behind as a residue. Thus it is clear that only the water evaporates, and if the water-vapour (or steam) is cooled, it condenses, and pure (distilled) water is obtained.

Water expands when heated from 4° C. up to 100° C. (boiling-point), and contracts when cooled from 100° C. down to 4° C. Below 4° C., however, it expands again, and at 0° C. (freezing-point) turns into ice, expanding during freezing to $\frac{12}{11}$ths the volume of the water. When a plant is exposed to great cold, the expansion of the water during freezing often forms cracks in the tissues or even causes the bursting of the cells themselves. The action of frost helps in forming soil from the underlying rock, and also breaks down the rough clods left by the plough into a fine seed-bed. If water contracted on freezing, the ice as it formed would sink to the bottom, and thus a spell of cold weather would convert our rivers, lakes, and pools into blocks of solid ice.

21. **Cooling caused by Evaporation.** It is well known that whenever a liquid is converted into vapour, whether by evaporation or boiling, heat is absorbed in the process. Whether heat be deliberately supplied or not, evaporation still proceeds—*e.g.* ponds and puddles dry up. The heat necessary to maintain this continuous process comes from the remainder of the liquid or any body with which the liquid is in contact. Thus a liquid by evaporating tends to cool itself and surrounding bodies. Several experiments have been devised to illustrate this fact.

Exp. 32. Pour a few drops of ether on to the hand, and then wave the hand. This will produce a sensation of cold, as ether evaporates very readily.

Exp. 33. Pour a few drops of water on a wood block, and stand in this water a beaker containing a little ether. Then blow with a bellows into the beaker to quicken the evaporation of the ether. The water will freeze and cement the beaker to the wood.

22. **Conditions favourable to Evaporation.** Evaporation is increased by anything that helps in the formation of vapour at the free surface of the liquid. The rate of evaporation is therefore favoured by:

1. Dryness of the air.
2. Low atmospheric pressure.
3. High temperature, both of the liquid and of the air.
4. Large extent of free surface of liquid.
5. Low boiling-point of liquid.
6. Renewal of air in contact with surface of liquid.

23. **Conduction and Convection.** Water is a bad conductor of heat (Exp. 34), but is rapidly heated uniformly throughout if *convection* currents are set up (Exp. 35). When heat is applied to the bottom of a vessel containing water, the lower layers, being heated, expand, become lighter and rise to the surface, while the heavier cold water steadily descends to be warmed. In nature, however, ponds and streams are warmed and cooled from the top, so that the surface layers may become quite warm while the bottom layers are very cold. In winter time as the surface water cools and becomes heavier it descends, the warmer water rising from the bottom, and this goes on until all the water is at 4° C. Then the surface layers begin to expand and a layer of ice forms, which keeps in the heat of the water beneath. Hence it requires very great and prolonged cold to freeze through a deep pond.

Exp. 34. Load a piece of ice by twisting a piece of copper wire round it, and sink it in a long tube nearly full of water (fig. 13).

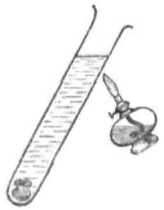

Fig. 13.

Fig. 14.

Fix the tube in an inclined position on a retort stand, and heat it near the top by a spirit lamp. It will be found that the top may be boiled before much of the ice is melted.

Exp. 35. In a beaker of water strew some paper pulp or sawdust. Place it on a piece of wire gauze on a tripod stand, and when the water has become nearly still, put the flame of a Bunsen burner under the middle of the beaker (fig. 14). Note the ascent of the warm water up the middle of the beaker, and the indraught of cold water from the top and sides.

24. **Specific Heat.** Of all substances water has the greatest capacity for heat, and, if its capacity be taken as unity, the relative capacity of any substance is called the *specific heat* of that substance. Or the *specific heat* of a substance is the ratio between the amount of heat required to raise a given mass of the

substance 1° C. and the amount of heat required to raise an equal mass of water 1° C. The same amount of heat that will raise the temperature of 1 lb. of water from 0° to 1° C. will raise 1 lb. of sand from 0° to 5° C.

Owing to its great specific heat, water absorbs much more heat in warming, and gives out much more heat in cooling, than an equal weight of almost any other substance. Hence the value of water in hot-water pipes, foot-warmers, etc. The same fact explains why island countries enjoy a more equable climate than continental countries in the same latitude; since land is more easily heated or cooled than water.

25. **Unit of Heat.** To compare the heat capacity of any substance with that of water, we take equal masses, and we may take as *unit quantity of heat* the quantity required to raise a certain mass of water 1° C. in temperature.

The mass usually taken is 1 gm., and the thermal or heat unit so defined is known as a *calorie*. If it be more convenient in working out an example, 1 lb. or 1 oz. may be taken as the unit of mass instead of 1 gm.

26. **Latent Heat.** We saw that when ice at 0° C. has heat applied to it, its temperature does not rise so long as any ice is unmelted; the heat energy supplied is used up in changing the solid ice into liquid water. About 79 heat-units are required to melt 1 lb. of ice into water at 0° C. When water has been brought to the temperature of boiling, it ceases to become warmer so long as boiling continues; the heat supplied is used up in doing the work of changing water into steam. About 537 heat-units are required to change 1 lb. of water at 100° C. into steam at the same temperature. The amounts of heat required to change ice into water and water into steam are called the latent heats of ice and of steam.

There are some familiar effects connected with the magnitude of the latent heat of water. After all the water in a pond has cooled to the freezing temperature, a long time elapses before any great thickness of ice is formed, even if the frost be severe. The great amount of heat latent in the water takes time to radiate. One of the reasons why snow lies permanently on high mountains is that the latent heat of water is so great that neither the sun's rays nor warm winds are able to provide sufficient heat to melt all the snow that falls in a year.

27. **Solution.** When a lump of sugar is placed in water, essentially the same thing happens as in the evaporation of water. The sugar absorbs heat from the water, and this causes the surface particles (molecules) of sugar to vibrate so rapidly that the attractive force which keeps them together is weakened, and they are drawn outwards by the water and dissolved. Since solution is due to absorption of heat, it follows that, in general, the higher the temperature the more rapid will the process of solution become.

Hence soluble salts for plant food in the soil will be formed more rapidly when the soil is warm than when it is cold. If you keep on adding sugar to water, there comes a time when there is no increase in the strength of the solution. Just as many molecules of sugar pass from the solution and become attached again to the solid sugar as are thrown from the solid sugar into the solution. The solution is then said to be saturated.

28. **Diffusion.** When water has evaporated into the air, or when sugar has dissolved in water, there is a tendency for the separated molecules to travel in all directions until they are equally distributed. A lump of sugar placed in the bottom of a cup of tea will in time make all parts equally sweet, without any stirring. This scattering of molecules is called diffusion; it varies with temperature, and differs in different substances. If oil be poured on water, no tendency to intermix is observed, and even if the two liquids be violently shaken together, two separate layers are formed on allowing them to stand. With alcohol and water the case is different. If alcohol, which is lighter, be carefully poured on water, so as to form two distinct layers, it will be seen that the heavier water "rises" in opposition to gravity, while the lighter alcohol "sinks" into the water below, and thus the two liquids gradually mingle, in spite of the difference of their specific gravities; they diffuse into one another.

Exp. 36. The slowness with which diffusion occurs in still water is shown by partly filling a tall narrow jar with water, and with the help of a long thistle-funnel running in very slowly a layer of a strong coloured solution, *e.g.* a concentrated solution of potassium dichromate or of copper sulphate; the colour spreads to the upper layers very slowly if the jar is left undisturbed. How could you hasten the process of diffusion without shaking the jar?

Exp. 37. Into a tall jar pour water coloured by solution of blue litmus, and with the thistle-funnel pour in some sulphuric or hydrochloric acid, so as to form a layer at the bottom. The colour of the solution is changed to red, progressing upwards, and after a time the change is complete, showing that the acid has diffused through the whole mass.

29. **Laws of Liquid Diffusion.** The general results of experiments on diffusion of liquids may be thus stated: (1) when solutions of the same substance, but of different strengths, are taken, the quantities diffused in equal times are proportional to the strengths of the solutions; (2) the quantity diffused varies with the temperature, *e.g.* taking the rate of diffusion of hydrochloric acid at 15° C. as unity, at 49° C. it is 2·18; (3) if liquids be dilute, a substance will diffuse into water containing another substance dissolved, as if into pure water, but the rate is greatly reduced if a portion of the same diffusing substance be already present. The following gives the approximate times of equal

diffusion: hydrochloric acid, 1; common salt, 2·3; cane sugar, 7; Epsom salt (magnesium sulphate), 7; albumen, 49. Substances like albumen, starch, dextrin, gum, etc., which diffuse very slowly, have been called *colloids*, in contrast with the far more easily diffusible *crystalloid* substances. Colloids are further characterised by their incapacity for taking the crystalline form and by their gummy nature. Substances of very unequal diffusibility may be separated by using the method of *dialysis*. A *dialyser* consists of a ring of gutta-percha or glass, over which is stretched a sheet of parchment paper, forming thus a shallow vessel, the bottom of which is of parchment. After pouring in the mixed solution to be dialysed, the whole is floated on water in a large vessel; in a day or two a more or less complete separation is effected.

30. **Osmosis.** When dry raisins are placed in water, they swell up just as dry seeds do. On the other hand, if fresh grapes are placed in a strong solution of sugar, they shrink. The swelling of the dried seeds or raisins and the shrinking of the fresh grapes are due to *osmotic pressure*, which is caused in essentially the same way as gaseous pressure. In order that the molecules of a dissolved substance may exert this pressure, the solution must be weak, so that the molecules are too far apart to attract each other strongly, and the dissolving substance and the substance dissolved must be separated by a membrane through which the molecules of one of the liquids pass more readily than those of the other.

Osmosis may be defined as diffusion through a permeable but non-porous membrane. If we place in a vessel of water a bladder filled with a strong solution of a substance having an attraction for water (an osmotically attractive substance), *e.g.* sugar, a *large* amount of the water will diffuse (pass by osmosis) into the bladder (*endosmosis*), while a *small* amount of the solution will diffuse out (*exosmosis*). The weaker solution diffuses faster, and this continues until the same concentration is acquired, when it is equally rapid in both directions, and hence apparently ceases. Meanwhile considerable pressure is set up inside the bladder, owing to rapid endosmosis.

Exp. 38. Cover the mouth of a thistle-funnel with parchment, or pig's bladder, and tie it on tightly. Invert the funnel, and with a pipette add sugar solution till it reaches a short distance in the tube of the funnel. Mark the level with a strip of gummed paper, then set the funnel in a dish of distilled water; or, better, pass the tube of the funnel through a hole in a cork so that the head of the funnel dips into the water. Observe the rise of the liquid in the tube of the funnel, also show that a little of the sugar solution diffuses into the water, by evaporating the liquid in the dish to dryness, when a small residue of sugar will remain. If the sugar solution used is strong enough, the presence of sugar in the water outside of the thistle-funnel may be detected by tasting.

31. **Osmotic Pressure.** Careful experiments with suitable membranes have shown that the osmotic pressure set up by a 6 per cent. solution of cane-sugar (*i.e.* a solution of which 100 grams contain 6 grams of sugar) equals 60 lb. per square inch, enough to support a column of water about 140 ft. high, while a 3 per cent. solution of saltpetre produces a pressure of about 70 lb. per square inch. Some idea of osmotic pressure may be obtained by using apparatus fitted up on the same lines as those shown in fig. 15, the pressure being measured by the rise of the mercury in the bent tube. The pressure set up by endosmosis has an important application in connection with root-absorption (Ch. III.).

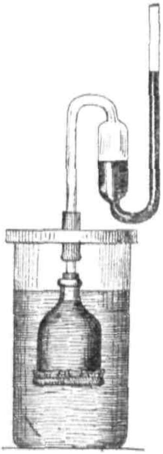

Fig. 15.

32. **Surface Tension.** The free surface of water (and other liquids) behaves much as though it were covered by an elastic membrane (surface film). It is this surface action that draws the raindrop into the form of a sphere as it falls through the air, and that causes water to form into spheres on a dusty floor or on the leaves of many plants (see Ch. IV.). The cause of surface tension is the attraction of the particles (molecules) of water for each other. This attraction extends throughout the liquid, but only the molecules at the surface show its influence, because it is only these that are not pulled evenly in all directions by water-molecules on every side.

33. **Capillarity, or Capillary Attraction.** When open glass tubes, having a very small bore, are held vertically in a liquid, there is always a difference between the level of the liquid inside the tube and that of the liquid outside. If a glass tube of this kind be placed in water, the level of the water in the tube will be above that of the water outside, and the surface of the water in the tube will be concave (fig. 16 *a*). In the case of mercury, the level inside will be below that outside, and the surface will be convex (*b*). The finer the tube, the more marked will the result be. The liquid only ascends when it is capable of wetting the sides of the tube. Hence we have two kinds of capillary action—in one the liquid wets the tube, ascends, and has a concave surface, in the other it

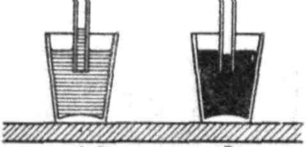

Fig. 16.—Capillary Attraction (*A*) and Repulsion (*B*).

does not wet the tube, descends, and has a convex surface.* We need only deal with the capillary ascent of water, which is of importance in plant-life. If the tube (supposed circular in cross section) is 1 in. in diameter, the water rises 0·054 in.; if 0·1 in. diameter, the water rises 0·54 in., and so on. In a tube 0·001 in. diameter, the water rises 54 in. This capillary action is closely connected with the surface tension of the water, and it is therefore natural that the total lifting force which supports the column of water should be proportional to the circumference of the tube. The circumferences of tubes increase in the same proportion as their diameters,† hence a tube 0·1 in. diameter will lift above the water-level ten times as much water as a tube 0·01 in. diameter. But the area of the water-column increases as the *squares* of the diameters of the tubes,‡ hence the wider tube will only lift its column one-tenth as high as the narrower one, its load being then ten times as great. The following table shows the relation between the diameter of a cylindrical capillary tube, the volume of water raised, and the height of the water-column:

Diameter of tube.	Volume of water raised.	Height of water-column.
1·0 in.	0·0429 cubic in.	0·0546 in.
0·1 ,,	0·00429 ,,	0·546 ,,
0·01 ,,	0·000429 ,,	5·46 ,,
0·001 ,,	0·0000429 ,,	54·6 ,,

Exp. 39. *Capillary Tubes.* Fix upright in coloured water a few clean glass tubes whose bores vary in diameter from an inch down to that of thermometer tubing. It will be found that the water rises a little way up even the widest tube; whilst in the smallest it mounts an inch or more above the outside level. The smaller the bore the higher the water rises.

34. **Amount of Water absorbed by Seeds.** When a dry seed is placed in water, how much does it absorb, and what proportion do the weight and volume of the absorbed water bear to the weight and volume of the dry seed?

* Very fine tubes that show this phenomenon well are called *capillary* (*i.e.* hair-like) *tubes*, and the phenomenon is known as *capillarity* or capillary attraction and repulsion. The "soaking up" of ink by blotting-paper is an example of capillary attraction, the fibres of the blotting-paper being really minute tubes, whose substance is "wetted" by the ink, so that the level of the liquid rises considerably in the tubes. Other cases are the "sucking up" of water by a lump of sugar, the rising of the melted wax in the wick of a burning candle or of oil in a lamp-wick, and the diffusion of water through soil.

† Circumference of a circle = 3·14 × diameter.

‡ Area of a circle = ·785 × square of diameter.

Exp. 40. Weigh twenty dry beans; pour water into a graduated vessel until it reaches the 150 c.c. mark, then drop in the beans, and shake the vessel to get rid of any air present; the rise in level gives the volume of the beans. Take them out and place them in moist sawdust for two days, then wipe them dry, weigh them, and find their volume as before. If you have no graduated vessels, use a glass jar with a strip of paper, marked into inches or centimetres, gummed on the outside of the jar. Beans absorb 1·2 times their own weight and volume of water, or even more than this.

35. **Where Water enters the Seed.** When dry beans or peas are placed in boiling water, air escapes from the micropyle; sometimes air-bubbles also come from the scar. When a dry seed is placed in water or moist sawdust or soil, does the water enter solely by the micropyle, or partly by the scar, or does any enter by the rest of the seed-coat?

Exp. 41. In a box of moist sand, which must be kept moist by adding water every day, plant three rows of beans, those in the first row with the scar end downwards, those in the second with the scar end upwards, those in the third laid flat with the scar at one side. Press them all into the sand so that each seed is half buried in it, and compare the germination of the seeds in the three rows.

Exp. 42. Weigh a number of dry beans and fix them into notches cut round half the circumference of a flat cork; about half of each seed should dip into the water, with the scar end downwards. Weigh an equal number of seeds and fix them into the rest of the edge of the cork, but with the scar end upwards, well out of the water. After a few days, remove each lot of seeds separately, wipe them dry, weigh, and compare.

Exp. 43. Could water enter by the scar if the micropyle itself were sealed up? Seal the micropyle in some dry seeds (weigh before and after sealing) with sealing-wax, plasticine, rubber solution (or tyre-mending cement); put the sealed seeds in water along with some unsealed dry seeds which have also been weighed. Try two other lots in which the sealing substance covers (1) the scar but not the micropyle, (2) both scar and micropyle. You should wipe dry and weigh the sealed and unsealed seeds at intervals, to find out which lot is absorbing water most rapidly and which most slowly. When unsealed seeds have absorbed the maximum amount of water (about 120 per cent. for Broad Bean), seeds with sealed micropyle that have been in water for the same length of time will have absorbed only about 60 per cent.

36. **How Water enters the Seed**. If you put some dry seeds into a jar, fill the jar up with water and let it stand open for a week or two, you will notice that the seeds swell up but do not germinate (the radicle may burst through the seed-coat), and a scum forms on the surface of the water, which after a time becomes cloudy and ill-smelling. The scum, cloudiness, and bad smell are due to the presence of "germs," or *bacteria* (see Ch. X.), which have evidently entered from the air, though some may have been present in the water (unless it was boiled for some time) or on the seeds (unless they were washed with formalin or other substance that kills germs). We shall see later that most bacteria can only grow in the presence of organic matter; hence the seeds have not merely absorbed water, but have also lost some organic matter, which has passed into the water around them. This loss occurs even when the micropyle is sealed up; hence it would appear that *osmosis* has occurred through the seed-coat.

Exp. 44. Carefully compare the increase in *weight* and the increase in *volume* that occur when dry seeds are placed in water. In an experiment, twenty-five Broad Bean seeds were found to weigh 61·8 grm.; after being kept at 45° C. in a drying oven for two hours they weighed 56·2 grm., and as this weight was again found on weighing half an hour later it was taken as the actual dry-weight of the seeds. The seeds were placed in water, which was renewed every day, and after five days the soaked seeds were dried at 45° C. till they showed a steady weight of 51·3 grm. This means that nearly 10 per cent. of the solid matter of the seeds had diffused into the water.

Exp. 45. Take some seeds that have soaked for a few days, and with a razor or sharp knife cut across each seed so as to divide it into a lower half (scar end) and an upper half. Slip off the coat from each half-seed, so as to get a number of cup-like pieces of seed-coat, some having the scar and micropyle, the others not.

Exp. 46. Get a sheet of glass and mark out on it, in ink, a circular space which will cover the top of a tumbler or glass jar. Within this circle fasten to one side of the glass, with sealing-wax or plasticine, the edges of the empty half-coats, including some of the lower and some of the upper halves. Nearly fill the tumbler or jar with water, and invert the glass sheet over it, so that the coat-halves touch the water. In the lower halves, water enters the micropyle by capillarity and is seen to accumulate as a drop inside the piece of seed-coat; this is more easily seen if some eosin or red ink has been added to the water. Does any water pass through the *upper* halves?

Exp. 47. Fix to a glass sheet in the same way some upper halves of seed-coats, after putting into each a piece of sugar. Take care to have the edges of the half sealed quite water-tight to the glass. Does the sugar "draw" water through the coat—*i.e.* does osmosis take place? Repeat the experiment with some upper halves into which you have put some strong solution of sugar or salt, coloured with red ink; each cup-like piece of seed-coat should be about one-third full of the coloured solution. Notice that the solution increases in amount, and that some of the colour appears in the water, showing that osmosis has taken place.

Exp. 48. Do the cotyledons in the intact seed "draw" water through the coat as the sugar or salt does in the case of the empty halves of seed-coat experimented with? Cut some dry seeds across and fix the upper halves to the glass sheet without removing the cut pieces of cotyledon. Weigh the half-seeds before attaching them to the glass, and again after two days.

37. **Capillarity and Osmosis in Seeds.** The foregoing experiments will show that water enters the seed partly by capillarity and partly by osmosis. The radicle, which is just within the micropyle, receives water more quickly than the other parts. The pocket around the radicle doubtless helps to draw water in by capillarity, thus making and keeping the radicle moist. Water also enters by osmosis through the seed-coat, and at the same time part of the solid matter contained in the young plant passes out, in solution, into the water. This substance which escapes from the seed is largely cane-sugar in the case of the Broad Bean. When the cargo of a wheat-carrying ship becomes damaged by water on a voyage, the weight of the wheat when dried again is found to have suffered considerable loss by sugar passing out into the water. We shall see later how the bean seed and wheat grain come to contain sugar after soaking in water.

Exp. 49. Do seeds absorb water more quickly if deprived of their coats? Compare the weights of water absorbed by whole beans and beans with the seed-coat removed, or by whole peas and "split peas"; it will be evident, if equal weights of whole and coatless seeds are placed in water for two hours, that the coat is a considerable hindrance in absorption.

Exp. 50. It will be noticed that as the seeds absorb water, they swell considerably, and this swelling takes place with considerable force. If a small, loosely made wooden box (*e.g.* a cigar-box with

the lid fastened down by tacks) is filled with dried peas and then immersed in water, it will burst as the peas absorb water and swell, for a large mass of swelling peas may lift a weight of more than 100 lb.

Exp. 51. The force exerted by swelling seeds can be also shown by filling an ordinary narrow-necked bottle with peas, and placing it under water in a basin; the bottle should be left uncorked, and some rubber bands should be put round it to prevent the shattered glass from being thrown out. Another method is to fill with dry peas an empty rabbit-skull and let it lie in water; the bones will be torn apart, or disarticulated, along the seams (sutures) where they join each other.

Exp. 52. How is the absorption of water by seeds affected by temperature? Weigh about 30 grm. of dry horse-beans or peas, place them in a beaker of water at 35° C., set the beaker on a sand-bath with a thermometer in the water, and keep the temperature steady at 35° C. for two hours. At the same time place an equal weight of seeds in cool water, with a thermometer; first let the water stand for a time till it acquires the temperature of the room. At the end of two hours, wipe dry both lots of seeds and compare the increase in weight in each case. The seeds that have been kept in water at 35° C. will have absorbed from two to three times as much as those kept in the cool water.

Exp. 53. *Structure of Bean Seed-Coat.* Remove the coats of two soaked seeds, and with scissors or pocket-knife cut out from one a strip including the scar, from the other a strip including the micropyle and the pocket into which the radicle fits; also cut strips from other parts of the coat. Hold each strip between two pieces of elder-pith or of carrot, and with a razor that has been dipped in weak alcohol (equal parts of methylated spirit and water) cut thin slices, or sections, sliding the edge of the razor across the strip and the embedding material; mount the sections in water, cover, and examine with the microscope (see Appendix IV.). Notice the outer layer (epidermis) of cells, which are greatly elongated vertically to the surface of the coat and have very thick walls; below this comes a layer of curious cells, each shaped rather like a cotton-reel or a capital letter I as seen in section, the cells being separated by air-spaces; below this layer there are several layers of smaller cells. Up the back of the seed (the side opposite the radicle) there runs, in the inner zone of the seed-coat, a bundle of narrow cells representing the vein which came from the stalk to supply the ovule and young seed with food. In a section across the scar, notice the large mass of pitted cells, the remains of the vein which entered the young seed from the stalk. In a section that has passed through the micropyle and the radicle-pocket, the inner wall of the pocket is seen to be formed by an ingrowth of the inner zone of the seed-coat, and the bottom of the pocket leads to the micropyle by a fine canal.

38. **Air required for Germination.** The seeds in your germination jars and boxes are exposed more or less freely to air. Is air necessary for germination? It is very easy to find out.

Exp. 54. Drop some seeds into a glass jar or wide-necked bottle, fill up with water and cork tightly. As a control, put some soaked seeds into a similar jar, leaving it open and adding a little water each day to prevent the seeds from becoming dry, but not enough to cover them. Ordinary tap-water contains dissolved air, but as a rule seeds immersed in it, in a corked bottle, do not germinate; to make sure that no air reaches the seeds, the water should be previously boiled to expel the dissolved air, and the cork sealed air-tight with vaseline or plasticine.

Exp. 55. Drop some dry seeds into water which has just been boiled, or place them in cold water and heat it over a flame until it boils. To hold the seeds down, fix them into a spiral coil of wire, easily made by winding iron or brass wire round a tube or a stick. Notice the air which escapes in bubbles from the micropyle; the dry seed contains some air, but evidently not enough to enable germination to begin, even when the seed is kept moist.

39. **The Atmosphere.** As the life-processes of plants (and animals) depend on a supply of air, and are greatly influenced by changes in it, the properties and composition of air must be thoroughly understood by the student of plant-life. Beans get about 97 per cent. of their food from the air, directly or indirectly; the water is brought to the roots in the soil as rain; carbon and nitrogen, two essential elements in the plant's food, come from the air, as we shall see later. In fact, the only portion of the bean's substance that does *not* come from the air is the 3 per cent. consisting of the ash-ingredients.

40. **Air is Material.** It is difficult for many young students at first to realise that air is as much a material thing as the water and earth around them. It does not equally appeal to the senses. Gases with striking properties do not present the same difficulty. The colour of chlorine, the odour of coal-gas, convince him of the reality of these. But the ever-present air, without odour, taste, or colour, occupies in the mind of the beginner a position quite by itself. The difficulty is increased too by such familiar phrases as "empty bucket," "nothing in the jug," etc. All will recognise that a stone must be removed before another body can be put in its place; some, that water is displaced when other bodies are dropped into it; but probably none are conscious of doing an exactly similar thing to air when they pour water into an "empty bucket."

41. Air has Weight. Physicists tell us that *all* material things, or "matter" as they call it, possess weight. If therefore we can show that air can be weighed, it will help to convince us of its material nature. It might occur to you that this could be done by weighing a bag first empty and afterwards filled with air. The ancient philosophers tried this way and found that the weight did not alter; they therefore concluded that air has no weight. This was an error, and shows us the danger of making statements without testing their truth in several ways. Instead of using a collapsible bag we will take a glass flask and use a delicate pair of scales or "balance" for the weighing.

Exp. 56. Select a flask rather large and preferably round. Fit it with a rubber cork pierced by a glass tube 3 or 4 in. long, over which is bound tightly a piece of rubber tube. Tie round the neck a piece of thin copper wire to hang the flask up by. Having seen that everything is quite dry and clean, hang the flask, together with another bit of wire, over the scale-pan of a balance, and very carefully weigh it.

Consider what we have weighed. There are flask, cork, glass and rubber tubes, three pieces of wire, and the air inside the flask.

Next suck out as much air as you can, using a glass mouthpiece so as not to wet the rubber tubing, which was weighed dry, and then double back the rubber tube, binding tightly the extra piece of wire round it to prevent air leaking back into the flask. Remove the mouthpiece and weigh the whole again.

The weight will now be found to be less than before. Since everything is present as at the first weighing, with the exception of the withdrawn air, it is reasonable to assume that the difference in weight represents that of the air sucked out.

But we can go farther than this. If you loosen the rubber tube whilst held beneath water, some of the latter passes into the flask, evidently taking the place of the removed air. Do this carefully, and measure the volume of water received by pouring it into a measuring vessel. The measurement evidently represents the volume of air sucked out, and we now know both weight and volume of this air. From your results calculate the weight of a litre of air; if your experiment has been carefully done, your answer should be somewhere near 1·3 grm.

42. The Pressure of Air. If, then, the air has, in common with solids and liquids, the property of weight, how great must be the downward pressure of the atmosphere which extends in appreciable quantities to the height of a hundred miles above the earth! Air presses against everything it touches. The magnitude of the pressure is independent of its direction; it is as great *laterally* and *upwards* as it is *downwards*.

Exp. 57. The machine called an "air-pump" is designed to remove air from the interior of vessels, and it does so far more effectively than mouth suction. The strong glass vessel from which we remove more or less of the air stands on a greased glass plate, and is called the "receiver"; the grease makes an air-tight fit.

Place within this receiver a rubber bag only partly filled with air

and with its mouth securely tied. The bag appears collapsed. But proceed to exhaust the receiver and note what happens. The bag fills out and the walls become *stretched*, evidently by the air left within it and whose pressure thus becomes apparent directly we remove a little of the air around it.

On allowing air to re-enter the receiver and exert its full pressure once more, the bag is squeezed back to its original limp state.

Exp. 58. Tie securely a piece of thin sheet rubber over the open top of the receiver. Grease the ground edge of the receiver before placing it on the plate of the pump. Give a few strokes of the piston to remove a little of the air from the receiver, when evidence of outer air-pressure will be obtained.

Exp. 59. Fill a small jar or tumbler with water; place a card over the mouth and invert it. Why does the water not run out?

43. **The Barometer.** The first actual measurement of the pressure of the atmosphere is due to Torricelli (1643), and his experiment resulted in the invention of the mercurial barometer.

A glass tube about 33 in. long and closed at one end is completely filled with mercury. The open end is then closed with the thumb, the tube inverted into a cup of mercury, and the thumb then removed, care being taken not to allow any air to get into the tube. The mercury at once sinks and leaves a clear space at the top of the tube, and the height of the column of mercury above the surface in the cup is found to be about 30 in. or 760 mm. The space above the mercury is practically a vacuum; it contains a minute quantity of mercury vapour. Hence there is no pressure on the top of the mercury column. The pressure of the air on the mercury in the cup must be equal to that due to the weight of the column of mercury in the tube. The height of this column therefore measures the weight or pressure of the atmosphere, and if the tube is furnished with a scale for reading off the height of the mercury, the apparatus is a mercurial barometer. If the tube is of uniform bore, and say 1 sq. cm. in section, the mercury in the column will weigh 1033 grm.; a water column of equal section and 76 cm. high will weigh 76 grm., and mercury is 13·59 times heavier than water. So the air-pressure per sq. cm. is 1033 grm.; or, in our system of weights and measures, with a tube 1 sq. in. in section, the mercury column (nearly 30 in. long) would weigh nearly 15 lb.—that is, the air-pressure is nearly 15 lb. per square inch.

44. **Air-Pressure Varies.** Having filled a tube a metre long with mercury and inverted it in a dish, if you measure the column from day to day, you will scarcely ever find two succeeding measurements exactly the same. Yet under ordinary circumstances it will always be somewhere between 28 and 31 in. It is evident, therefore, that the air-pressure, though always considerable in amount, is not constant, but may vary between fairly wide limits. As these variations have considerable effect upon the weather, it is important that they should be constantly noted.

45. **Barometers.** These are instruments designed for this purpose. There are two kinds, of which the **mercurial barometer** depends upon the principles just explained. The simpler forms of this instrument resemble the bent tube (fig. 17), and are known as "siphon barometers." A scale for reading the length of the mercury column is either etched upon the tube itself, or is affixed behind it. If, as rarely happens, the tube is constant in bore, the scale is necessary only for a few inches at the top. A rise or fall, say of 1 cm., really shows a difference in length of the column of 2 cm.

"Cistern barometers" are practically straight tubes inverted in open vessels of mercury. In Fortin's barometer there is an arrangement for bringing the surface of the mercury in this vessel to a fixed position, so that the top reading only is necessary.

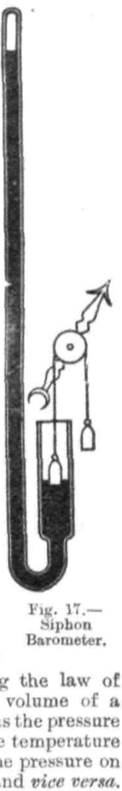

Fig. 17.—Siphon Barometer.

The **aneroid barometer** is now very commonly used, on account of its portability. No mercury is used in its construction. It consists of an air-tight metal box, generally disc-shaped, and almost exhausted of all air. The top is so flexible as to respond to the variations of the air-pressure upon it, and the slight movement in or out is magnified by a system of levers and communicated to a pointer which travels over a dial. The scale on the latter must be so fixed that the indications of the pointer correspond with the heights shown by a mercurial barometer.

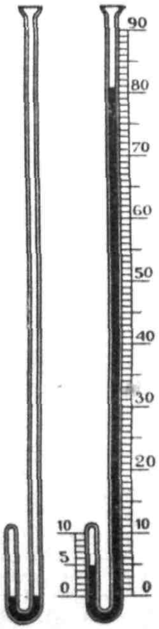

Fig. 18.—Illustration of Boyle's Law.

46. **Effects of Pressure and Temperature on the Volume of Air.** Air agrees with other gases in obeying the law of Boyle and Mariotte—*i.e.* that the volume of a given weight of gas varies inversely as the pressure to which it is subjected, provided the temperature remains the same. That is, when the pressure on air is doubled, its volume is halved, and *vice versa*.

Exp. 60. This law may be verified by means of the bent tube (sometimes called Boyle's tube) shown in fig. 18. The gas to be experimented on is placed in the shorter closed limb, and the quantity of mercury in the bend is adjusted so that the level, in each limb, is at the zero of the corresponding scale and also in the same hori-

zontal line. Mercury is then poured into the long limb, and it is found that as the pressure on the gas in the closed tube is increased its volume diminishes, and by observing the volume corresponding to different pressures the law given above will be found true.

It is well known that air expands when warmed. Accurate experiments have shown that dry air (and other gases) expand about $\frac{1}{273}$ of their volume at 0° C. for every increase in temperature of 1° C. and contract by the same amount for every decrease of 1° C. below 0° C., provided that the pressure remains the same. This is known as the law of Charles.

47. **Wind.** The higher we ascend into the atmosphere the colder does it become. The passage of the sun's rays through the air causes little elevation of its temperature; but the low-lying strata receiving much warmth from the quickly heated soil rise upwards, while the cooler air above and that lying over the sea stream into its place.

The following experiment may serve to illustrate these convection currents of the air and at the same time show the principle upon which mines are ventilated.

Exp. 61. Make a hole towards each end of a well-fitting lid of a cigar-box. Place a piece of lighted candle in the box exactly underneath one hole, and stand a glass chimney over both. Now hold some smouldering brown paper over each chimney in turn, and note the direction of the air-currents. Next, place a piece of cardboard over one chimney and make the same observations as before.

48. **Diffusion** is the property of gases to mix thoroughly and completely even against gravity—*i.e.* a heavy gas will diffuse upwards and completely mix with a lighter gas, and a light gas will diffuse downwards and mix with a heavier one. For instance, if in fig. 19 the upper jar is filled with coal-gas, which is a light gas, and the lower jar with air, which is a comparatively heavy one, then, on removing the plates between them and allowing them to diffuse for about half an hour, the lower jar will contain just as much coal-gas as the upper jar, and both may be lighted. The same result would be obtained, after a longer time, if a partition of some porous substance, such as unglazed earthenware, were placed between the jars. It is found that the lighter a gas is the faster it diffuses, and that if a light gas is on one side of a porous partition and a heavier gas on the other, then the light gas will diffuse through into the heavy one faster than the heavy gas will diffuse into the light one.

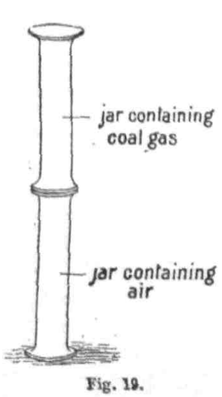

Fig. 19.

49. **Composition of Air.** Air consists chiefly of two gases, oxygen and nitrogen, together with other gases in smaller quantities. It contains varying amounts of water-vapour and of carbon dioxide, and traces of ammonia, nitric acid, etc.

50. **Oxygen.** When metals are heated in the air, they gain in weight; the ash (or *calx*, as it was formerly called) is heavier than the original metal. If a piece of magnesium ribbon is burnt in a closed vessel containing air and standing over water in a dish, the water rises in the vessel, showing that some of the air (about a fifth of the original volume) has united with the magnesium. Various other experiments prove that air consists of an active gas (oxygen) forming about a fifth of its volume, and of an inactive gas (nitrogen) forming about four-fifths of its volume. All ordinary processes of burning are accompanied by the absorption of oxygen from the air and its union with the burning substance. In most cases it is difficult to recover oxygen from the calx of a metal; partly on this account, the composition of air was not understood until late in the eighteenth century. In 1774 Joseph Priestley happened to heat some "red precipitate" with a "burning-glass" or lens, and found that a gas possessing remarkable properties was set free.

Exp. 62. Into a hard-glass tube introduce sufficient crystalline red precipitate to cover a threepenny piece, and hold it in the hottest part of the Bunsen flame. When cold, the substance is scarlet and glittering; but on heating it becomes black—it looks "*burnt.*" Take the tube from the flame, let it cool, and notice what happens. The scarlet colour is recovered. Evidently the change was not due to *burning*.

Have by you a splinter of wood long enough to reach down to the bottom of the tube, and heat the latter again as long as any of the oxide remains. Whilst the deposit is forming in the tube, ignite the splinter, blow out the flame, and thrust the glowing end down into the tube. Observe that the glowing splinter bursts into flame and burns more brightly than in common air. The colourless gas in the tube cannot be ordinary air: it is *oxygen*.

Now scrape off the mirror formed in the tube with the clean end of the splint. You obtain a liquid metallic globule of "quicksilver," or *mercury*.

51. In the same year as he made the above discovery, Priestley went to Paris and showed his experiment to the chemists there, among whom was the famous Lavoisier, who had proved that when metals are heated in air, the ash or scale (calx) formed is heavier than the metal and not lighter, as the old philosophers had assumed. This great chemist understood its significance, for he presently *made* some of the scarlet powder by heating mercury almost to its boiling-point whilst exposed to a *measured volume* of air. Specks gradually

appeared on the bright metallic surface, whilst the bulk of the air became less. At the end of twelve days he scraped off the rusty deposit, and, heating it strongly in a tube, *obtained the same volume of gas as the air had lost*, whilst the scarlet powder was transformed into the liquid metal again.

Plainly, then, this new gas, with its remarkable properties, is not merely a modified form of air, but is a distinct substance. Lavoisier gave to it its name oxygen, the "acid-former," for reasons to be given later. "Red precipitate" is a compound of mercury and oxygen, its chemical name being "oxide of mercury."

Oxygen is most readily prepared by heating potassium chlorate (a compound of potassium, chlorine, and oxygen).

Exp. 63. Heat some potassium chlorate in a tube until it appears to boil. It is not really boiling, or some of the substance should condense in the cool part of the tube. A gas is escaping. Test it with a glowing splinter as in Exp. 62.

Exp. 64. About one-quarter fill the tube with a mixture of two parts by weight of potassium chlorate and one of manganese dioxide. Oxygen will come off from this more readily than from the chlorate alone; that is, at a lower temperature than was required to decompose the chlorate alone. After all the oxygen is expelled the manganese dioxide remains, apparently unaltered, mixed up with the residue. As the gas is obtained so easily, we will collect some jars of it and examine its properties.

Exp. 65. Bend a glass tube, 9 in. to 1 ft. long, to the shape shown in fig. 20, and insert the longer end through a cork fitting a hard-glass tube closed at one end, about 6 in. long and 1 in. in

Fig. 20.

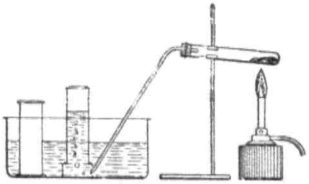

Fig. 21.

diameter. Pour sufficient water into a pneumatic trough to cover its shelf by at least half an inch. Fill one large jar and five smaller ones with water and invert them in the trough. Have ready some ground-glass covers to be placed over the mouths of the jars when filled with gas.

About one-quarter fill the fitted tube with the mixture made, and fix it horizontally in the jaws of a clamp, so that the delivery tube just dips under the shelf of the trough, as shown in fig. 21. Use a

small flame to heat the mixture, and move it to and fro along the tube to avoid getting too high a temperature. A few bubbles of air escape at first, but soon oxygen comes over rapidly. At once place a jar in position on the shelf, and, when filled, quickly cover its mouth while still under water with a glass plate, and replace it by a second jar, and so on.

Now try the effect of burning in oxygen three non-metallic elements (sulphur, phosphorus, carbon) and two metallic elements (sodium, iron).

Exp. 66. 1st jar (small). Fill the bowl of a deflagrating spoon with powdered *brimstone* and ignite it, noting flame and odour. Plunge it into the jar, and note that the brass plate fits closely (see fig. 22). When the action ceases, replace the glass cover. The flame and odour differ only in intensity from those first obtained. The sulphur has more or less burned away. Plainly the choking gas formed in both cases is due to the union of sulphur with oxygen. It is an oxide of sulphur. Pour a few drops of blue litmus solution into the jar: it turns red, showing that an **acid** is present. Invert the jar in water and remove the cover: the water rises as it readily dissolves the new gas.

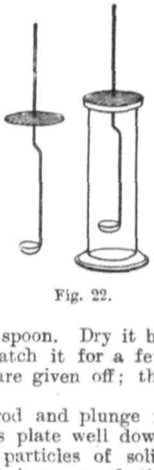

Fig. 22.

Burn off all the sulphur remaining on the spoon before proceeding.

Exp. 67. 2nd jar (small). Cut off from some yellow phosphorus, *held below water*, a piece not bigger than a pea, and transfer it on the point of a knife to the clean, cold deflagrating spoon. Dry it by touching it with a bit of filter paper, and watch it for a few seconds. White fumes with a peculiar odour are given off; the phosphorus is already reacting with the air.

Touch the phosphorus with a warm glass rod and plunge it immediately into the oxygen, keeping the brass plate well down on the jar. The white fumes are really tiny particles of solid *oxide of phosphorus*, and are poisonous. What becomes of the fumes? Test the water drops on the side of the jar with blue litmus paper. Evidently oxide of phosphorus, too, is acid-producing.

Exp. 68. 3rd jar (small). Wire a bit of *charcoal* to the end of a deflagrating spoon, and place it in the oxygen for a short time. Withdraw it, and note that no carbon dioxide can be detected. Cold charcoal does not react with oxygen. Now make the charcoal red-hot and watch it when removed from the flame. It does not go on burning as the other bodies did. Make it glow again and introduce it into the oxygen. Chemical action is now very evident, some of the charcoal disappears, but no odour or fumes are detected. Shake the remaining gas with water and divide the liquid into two

parts. Test the first with purple litmus, and the second with lime water. Carbon dioxide has been formed in plenty, and this oxide s acid-forming too.

Exp. 69. 4th jar (small). Examine *sodium*, noting its lustre when freshly cut and its lightness. This metal oxidises so rapidly in air that it must be preserved in liquid which contains no oxygen, and whose specific gravity is, of course, less than that of the metal. For these reasons liquid paraffin is often used. Sodium reacts violently with water, hence care must be taken not to handle it with wet fingers.

Heat a bit of the metal strongly in a dry deflagrating spoon, then plunge it into the oxygen. It burns brightly, forming white fumes *of sodium oxide which dissolve in water. Examine the solution* with litmus just coloured red by a drop of acid. The litmus at once becomes blue, indicating the presence of an **alkali.** Caustic soda is present.

Exp. 70. 5th jar (large). Introduce through a funnel sufficient sand to cover the bottom of this jar half an inch deep. Roll 8 or 10 in. of thin *iron* wire round a glass rod to form a spiral, and fasten a bit of match to one end. Attach the other end to a deflagrating spoon. Light the match and plunge the wire into the jar. The wire burns—often with beautiful scintillations—whilst white-hot globules of "burnt iron" (really iron oxide) fall upon the sand.

We have found that—

(i) the oxides of non-metals, like sulphur, phosphorus, and carbon, yield acid solutions with water; but

(ii) the soluble oxide of a metal gives an alkaline solution.

Lavoisier was not aware of this latter fact; but it was his knowledge of the former that caused him to give the name oxygen ("acid-former") to the gas.

Oxygen is only slightly soluble in water (100 c.c. of water at 0° C. dissolve about 5 c.c. of oxygen). It does not burn, but is a supporter of combustion; all substances that burn in air burn more vigorously in oxygen.

52. **Nitrogen.** The inactive portion of the air consists chiefly of nitrogen. No direct simple test can be given for the detection of nitrogen in the free condition, because it does not readily react with chemical reagents. It forms about a fifth of the volume of the air, and is neither inflammable nor a supporter of combustion. It has no action on lime-water nor on litmus paper. By the action of intense heat, or that of an electric current, however, it is caused to combine with oxygen, forming brown fumes of oxide of nitrogen, which dissolve in water to form nitric acid.

Nitrogen is a very important element in the nutrition of plants, since the living substance (protoplasm) of all plants (and animals) contains nitrogen. Most animals obtain nitrogen in the form of complex organic substances (proteids); most plants obtain it in the

form of simple inorganic substances (chiefly nitrates). Most plants are unable to use the nitrogen of the air in making food, but this power is possessed by some Bacteria, and probably the whole of the combined nitrogen found in nature (chiefly as nitrate of soda and potash) has been formed from the air by the action of Bacteria.

The composition of air varies very little under different circumstances; but even such small variations as are found in its composition do not occur in the case of chemical compounds.

Nitrogen and oxygen retain their characters with slight modification in air, and *a mixture of the two gases in the proper proportions shows precisely the same characters in all respects as air.* No heat is evolved when they are brought together, nor does any contraction in volume take place.

When air is shaken up with water, a greater proportion of oxygen dissolves than nitrogen, owing to the greater degree of solubility of oxygen; so that, whilst in the air originally taken one volume of oxygen is associated with approximately four volumes of nitrogen, air dissolved in water consists of one volume of oxygen associated with two volumes of nitrogen.

On all these grounds, therefore, we must admit that air is simply a *mixture* of nitrogen and oxygen, and not a chemical compound.

Exp. 71. The following experiment gives a useful method for depriving air of its oxygen, or of measuring the volume of oxygen present in air. Into a glass tube of about 100 c.c. capacity pour some 20 to 30 c.c. of solution of caustic soda, made by diluting that ordinarily used for analysis with twice its volume of water. Next, add as much pyrogallol as can be taken upon a penny piece. (Photographers will know this light fluffy powder as "pyrogallic acid.") Close the tube at once with a rubber cork, and mark the height of the liquid with a rubber band. Shake up occasionally for at least five minutes, then open the tube below water contained in a tall jar. Water enters; and if you sink the tube till the level of water inside and outside is the same, marking the position with another band, the remaining air will be found to occupy four-fifths of the original volume. On testing it as before, it will be found to be nitrogen.

Exp. 72. Invert a dry glass jar over a burning candle, both being placed on a table. After burning for a few seconds, the flame gradually grows less and soon goes out. Repeat the experiment with another jar lifted a short distance from the table; fresh air can now enter, and the burning continues. The extinction of the candle in the first case could not have been due to *destruction* of the air; since the fit is not air-tight, more air would have been pressed beneath the jar. It evidently remains full of "air" of some kind, yet differing from fresh air. The slightly raised jar not only admitted fresh air, but allowed the changed air to escape, on account of convection currents caused by the flame and by diffusion beneath the jar.

of the seeds, unsealed, on moist sawdust as a control. In which lot of seeds does germination first occur?

Exp. 78. Does air enter through the seed-coat? Cut across a soaked seed and fix the upper half of the empty coat, by means of sealing-wax, to the end of a glass tube, making the joint quite air-tight (test by blowing through it into water). Fill the tube with water that has been boiled (to expel air), then invert the tube so that the open end dips into a jar or tumbler of water. Does air pass through the seed-coat and appear at the top of the tube above the water?

Exp. 79. How much air is necessary to enable a seed to germinate? To answer this question, we may confine some seeds in closed vessels containing different quantities of air, and compare the results. Take four glass jars, all of the same size, and provided with well-fitting corks. Fill these jars to different heights with moist sand, marking each jar into five equal parts, and putting into the first jar enough sand to reach the lowest mark; into the second, sand up to the next mark; and so on. The fourth jar will thus contain four times as much sand, and therefore only a quarter as much air as the first. Into each jar now place three soaked beans, cork tightly, and seal with plasticine and vaseline. In which jar do the seeds germinate best? Do the results suggest that germinating seeds cause some change in the air, that they use the air up?

After three or four days, carefully remove the cork from one of the jars and lower a lighted taper or match into it; note what happens. Open another of the jars, and dip into it a glass rod which has been dipped into clear lime-water (see Exp. 72) or baryta-water (made by shaking up some barium hydrate with water, and filtering).

56. **Respiration of Germinating Seeds.** These experiments show that germinating seeds absorb oxygen and give out carbon dioxide, so that a germinating seed changes the air around it in the same way that an animal does by its breathing. Since the same change is produced by burning in air a candle (which contains carbon) or a piece of charcoal (which is practically pure carbon) we see that the respiration or breathing of a germinating seed, or of an animal, is simply a process of oxidation, a slow burning of carbon. Hence the seed must contain carbon in some form; we shall return to this point later. Meanwhile, here are some further experiments on the respiration of germinating seeds.

Exp. 80. Get a wide-mouthed jar with a tightly fitting cork; bend a glass tube twice at right angles, so that the two parallel legs will be of about equal length, and through a hole in the cork push one of

the legs until it nearly reaches the bottom of the jar (when corked). Fill a small muslin bag with soaked peas, mixed with bits of soaked sphagnum or clippings of wet sponge, and hang the bag to the lower side of the cork by means of a bent pin. Put a bit of sponge soaked in caustic potash solution * in a small wide-necked bottle or an egg-cup and lower it into the jar. Smear the top of the cork and the rim of the jar with plasticine. Put the outside tube in a tumbler or open bottle of water coloured with red ink; keep the apparatus in a fairly warm place, and note any visible result. After a day or two, when you find that no more water seems to be collecting at the bottom of the jar, raise the cork and insert a lighted taper. Now write out an exact account of what has happened during this experiment. What changes in the air have been wrought by the germinating seeds? Why does the water pass over through the bent tube from the vessel outside into the jar?

Exp. 81. In the last experiment the carbon dioxide produced by the germinating seeds was absorbed by the caustic potash solution in the sponge. Omit the latter this time; use the same jar, half fill the jar with soaked peas or beans, and fix the bent tube so that the end of one limb is above the level of the seeds, while the outer limb dips into a bottle containing lime-water or baryta-water. Set the apparatus in a warm place, and notice the bubbles of carbon dioxide which are given off, and which cause a white precipitate.

Exp. 82. Take three U-tubes and three narrow jars (or test-tubes a little wider than the U-tubes). Place in one arm of each U-tube six soaked seeds (peas or wheat), then invert the U-tube after inserting a cork, with a wad of soaked cotton wool to keep the seeds moist. Half fill the jars or test-tubes with (1) water, (2) strong caustic potash solution, (3) strong solution of pyrogallol in caustic potash, and place the open ends of the U-tubes in the test-tubes. If you have no suitable narrow jars, support the test-tubes in a stand. Notice that in (3) the solution soon rises in the inverted U-tube (how far does it rise, and why?) and the seeds germinate very little (why?); in (2) the solution rises, more slowly, and to the same extent (why?), and the seeds germinate well; in (1) the water hardly rises at all, though germination occurs as in (2). What has happened in each case? In (2) the seeds absorb oxygen from the air and give out carbon dioxide, which is absorbed by the potash solution, and the latter therefore rises slowly in the U-tube for about a fifth of its length; in (3) the potash and pyrogallol solution absorb the oxygen of the air in the U-tube. Why does the water not rise in (1)?

Exp. 83. In the foregoing experiments it is clear that normal germination does not occur unless the seed is supplied with air

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* This solution rapidly absorbs any carbon dioxide in its neighbourhood, but the carbonate of potash formed is *soluble*.

containing oxygen. In some cases, however, a slight amount of growth occurs even when the seeds are deprived of oxygen, and sometimes a good deal of carbon dioxide is given off under such conditions. This is easy to prove by the following experiment: Soak six peas (or horse-beans) in water for a day or until the coats can be removed without damaging the embryo. Fill a test-tube with mercury and invert it in a dish of mercury; then pass the seeds under the open end of the tube, when they will float up to the closed end. In a day or so the test-tube is half full of gas; what is this gas, and how has it been produced? With a bent tube pass a little water under the test-tube, so that it will float up to the surface of the mercury, then pass up a small piece of caustic potash; the strong potash solution thus formed absorbs the gas, and the mercury rises again to its original position. This production of carbon dioxide, in the absence of free oxygen, is called "intra-molecular respiration"; apparently in some way the substance of the embryo is decomposed in this process, and besides carbon dioxide, alcohol and other products are formed. This "intramolecular respiration" is very marked in peas and beans, but in all cases it is probably a process of destruction, without healthy growth taking place, and ends in death; it seems to be related to the process of fermentation (see Ch. X.).

57. **Heat produced by Respiration.** From the foregoing experiments it is clear that respiration is a process of oxidation, just as burning is, and this suggests that it may be accompanied by the giving out of heat. Do germinating seeds give out heat?

Exp. 84. Fit three tumblers or jars with a cork or a cardboard cover, with a hole in the centre through which a thermometer is passed. First compare the readings of the three thermometers by placing them together in water at different temperatures. Half fill one jar with soaked seeds (peas, beans, wheat, or barley answer well); the second with seeds that have been killed by boiling (add some corrosive sublimate to the water to prevent growth of moulds or Bacteria); the third with moist sawdust (as a control). Place the three jars, with thermometers inserted to equal depth in each, in a box, and put dry sawdust between and around them; cover the whole with a bell-jar or a dry cloth, and compare the readings of the thermometers at the start of the experiment and then at intervals of a few hours.

Exp. 85 (*another method*). Instead of jars or tumblers use three test-tubes, each with a bored cork for the thermometer; place the tubes horizontally in a cardboard box, with thermometer-stems projecting through holes, and pack round and between the tubes with dry cotton-wool.

58. **Air in the Soil.** The presence of air, containing oxygen, in the soil in which seeds are germinating is obviously essential if healthy growth is to take place; moreover, the air in the soil must be kept in circulation (why ?). Good ventilation is as necessary for germinating seeds, and for the roots of mature plants, as it is for the life and health of human beings. Not only is free oxygen in the soil required by germinating seeds and for roots, which, like them, must breathe, but many processes occur in soil that depend on the presence of oxygen. Nitrogen is required for the use of Bacteria, which fix free nitrogen gas and make nitrates, and these Bacteria, as well as others which convert the nitrogen of humus, manure, and other decaying organic matter into nitric acid, require large amounts of oxygen in order to do this work. The exchanges of gases between soil and atmosphere are brought about in several ways—*e.g.* the slow process of diffusion; expansion and contraction of soil-air due to changes in temperature and in barometric pressure.

Exp. 86. *To Measure the Volume of Air in Soil.* Get two glass jars of the same inside diameter. Pour water into one jar until it is rather less than half full, and mark its level. Mark a corresponding level on the other jar, which is to be kept quite dry inside, and put the soil into this jar until it reaches the mark. We have now equal volumes of water and of soil. Pour the soil slowly into the water; if the soil contains *no* air, it will make the level of the water rise to twice its original height, hence the amount by which it fails to do this measures the volume of air in the soil. Try this simple experiment with different soils (sand, chalk, clay, loam), and find the percentage volume of air in each soil. The soil should be well broken up—*e.g.* by crushing between the fingers—and should be spread out to dry before being placed in the jar.

59. **Influence of Depth of Sowing on Germination.** In the lower as compared with the upper layers of the soil we find less air, less circulation of air, and more water. How will the depth at which a seed is placed in the soil affect its germination ?

Exp. 87. Plant seeds in your glass-sided box at different depths. Put the seeds close to the glass, and (unless the glass has been fixed in with putty so as to be air-tight) put them near the middle of the glass. If the seed is buried too deeply it does not get enough air for healthy germination, and it is apt to be attacked by moulds.

60. **Effects of Heat on Seeds.** When a seed is exposed for a few hours to a moderately high temperature, all the water it contained is driven off, and the young plant is killed. We can only tell whether a seed is alive or not by finding out whether it will germinate when exposed to suitable conditions. Is the death of seeds kept on a water- or sand-bath, or in an oven, at say 40° C., due to the heat itself or to the total loss of water?

Exp. 88. Place in a small muslin bag a dry bean and a bean that has soaked for two days, and dip the bag into water which is boiling over a Bunsen or spirit-lamp. Try several pairs of seeds in this way, keeping them in the boiling water for different times (1 minute, 2 minutes, etc.), then plant them in your germination jars or boxes, with a suitable label on the glass above or below each seed. Find out in this way how dry and soaked seeds differ in their ability to withstand the effects of heat.

Exp. 89. A better plan is to place the dry seeds in a dry test-tube, the soaked seeds in a test-tube half filled with water; cork both tubes, and immerse them in a beaker placed on a sand-bath and kept at 60° C. for two hours (try several different temperatures and times). Then soak the dry seeds in water for a day or two and sow both lots.

61. **Effects of Cold on Seeds.** We find that dry seeds can withstand high temperatures which are fatal to soaked seeds. On placing seeds among ice or a freezing mixture, we find that dry seeds can also resist low temperatures that kill soaked seeds. It has been found that the dry seeds of many plants can germinate after being exposed for a long time to the most intense cold that can be obtained (about − 250° C.), while many soaked seeds are killed by exposure to the freezing temperature of water or a few degrees below this.

Exp. 90. Repeat Exps. 88 and 89, using a mixture of ice and salt instead of the hot water.

Exp. 91. Does the seed-coat help the seed to resist heat or cold? Repeat the preceding experiments, using and comparing complete seeds (dry and soaked), and similar seeds with the seed-coat removed.

62. **Warmth required for Germination.** When the temperature of the soil falls to 0° C., nearly all life-processes become dormant, and for most cultivated plants these processes do not begin until a temperature above 5° C. has been reached. There is for most plants a certain

range of temperature within which germination is most rapid, and which ensures the highest percentage of plants from the seeds sown. The temperature below which germination does not occur is called the *minimum*, that above which there is no germination is the *maximum*, while the most favourable temperature is the *optimum*; these might be called respectively the *lowest*, *highest*, and *best* temperatures for germination. Here are some examples:

	Minimum. °C.	Maximum. °C.	Optimum. °C.
Cress	2	28	21
Red Clover	6	28	21
Wheat	5	43	29
Turnip	7	42	31
Beans	5	46	33
Maize	9	46	34

In general, the temperatures at which the seeds of most cultivated plants grow best in our climate lie between 21° C. and 35° C., with an average about 28° C.

Exp. 92. Place some soaked seeds in a glass jar, and cover them with moist sawdust; plunge the jar into a box containing pieces of ice, which must be renewed as they melt. The ice will last longer if the box containing it is set into a larger box, and the space between the two boxes is packed with dry sawdust.

Exp. 93. Another method is to use two boxes as in the preceding, but to place in the smaller box a single block of ice, with dry sawdust below and around it; place the seeds directly on the ice and cover them with dry sawdust, which will be kept moist by the melting ice.

Exp. 94. In winter and spring the minimum temperature for germination should be determined for as many seeds as possible. Into a large flower-pot or seed-pan put some bits of broken earthenware at bottom, and fill up the rest of the pot with sifted soil. Plant in the pot a few seeds of different kinds, and bury the bulb of a thermometer at the depth of the seeds, tying the thermometer stem to a stick thrust into the soil. Sink the pot up to its rim in the soil of a garden bed and record the temperature each day, looking for any signs of germination. After two or three weeks bring the plants indoors; keep the soil moist; make notes of your observations. Other pots should be kept in different parts of the house or school, in addition to those kept outside. Such experiments will show that warmth hastens germination, while cold retards it.

63. **How Soil Temperature is Influenced.** The specific heats of different kinds of soil differ considerably. The following list gives the number of heat-units required to raise 100 lb. of dry soil from 0° C. to 1° C.: Peat, 22; humus, 21; pure chalk, 18; sandy humus, loam, pure clay, each about 14; sand, 10. It is clear that much more heat is required to raise the temperature of water through 1° than that of the same weight of dry soil; hence a dry soil will warm in the sunshine more rapidly than a moist soil.

A dark-coloured soil is warmer than a light soil, and shows a greater daily variation in temperature. The degree of inclination of the surface and the direction of the slope often exert a marked influence on the temperature of the soil, and especially on its daily range. The effect of a south exposure is to make a difference of 2° or 3° C. in the first foot or more at the surface. When the surface of the soil is very uneven, its heat is lost more rapidly in warming the air above it. If the soil is loose and open in texture, the drier surface layer loses heat to the air, while the poor conducting capacity of the open soil prevents the heat from being conveyed deeply below the surface, and a lower temperature results. If the air is warmer than the soil, as often happens in spring, a large amount of heat may be conveyed rapidly into the soil with rain-water.

Except direct sunshine on the one hand, and direct radiation of heat away from the earth on the other, there is no factor which exerts so strong an influence on the temperature of the soil as the evaporation of water from its surface. When a pint of water evaporates from a cubic foot of soil, it carries with it heat enough to lower the temperature of the soil considerably—if sandy soil about 20° C., if clay-loam about 15° C. To dry saturated sandy soil till it contains half its maximum amount of water requires the evaporation of about 9 lb. to the square foot when the drying extends to the depth of a foot; the similar drying of clay-loam requires the evaporation of about 12 lb. of water. It is largely owing to the latent heat of vaporisation of water and to the low specific heat of soil that a wet soil is cooler than the same soil when dry. When soil is rolled, its texture is made firmer, and it conducts heat better, so that

the surface layers become warmer; the temperature at a depth of 2 in. may be about 5° C., at 4 in. about 3° C., higher than in entirely similar and adjacent but not rolled soil.

64. **Hedges.** It is important that the velocity of the wind close to the surface of the soil should be reduced. Where fields are not sheltered by hedges, strong winds may sweep away the young crops, together with the upper few inches of surface soil—*i.e.* the best part of the soil. Hedges also lessen the rate of evaporation of water from the soil. The drying effect of wind at 300 ft. to the leeward of a hedge is sometimes 50 per cent. greater than at 20 ft. Since evaporation of water leaves the soil colder, the temperature will be higher close to the hedge than away from it. At the top of a hedge-bank, the light is feeble and the soil dry, but lower down there are moisture and light (see Ch. IX.). If the hedge has level ground on one or both sides, the differences in the amount of water at the base of the hedge and farther from it are less pronounced than when it grows from a raised bank with a ditch on each side.

65. **Daily Observations.** Besides observing the temperatures required for various germinating seeds in field and garden, you should find out the temperature of various kinds of soil at different depths (say at 3, 6, 12, and 24 in. from the surface), and record the average temperature (for each plot of soil and for each depth) during each month of the year. Also take thermometer readings throughout the year on the two sides of a hedge, at top and bottom of a slope, in ditches, streams, and ponds, and compare these carefully. Also keep a daily record of observations on humidity, rainfall, direction and force of the wind, barometric pressure, and temperature. Compare all these observations, and see how they are connected, or "co-ordinated," with each other.

66. **Maximum and Minimum Thermometers.** It is often necessary to know the highest or lowest temperature reached in a given interval of time. For instance, it is usual in making meteorological observations to record the highest (maximum) temperature attained during the day, and the lowest (minimum) temperature reached

during the night. For these purposes maximum and minimum thermometers are employed.

Six's maximum and minimum thermometer is one of the oldest of its class, and is at once a maximum and a minimum thermometer. Its general plan of construction is shown in fig. 23. The bulb B and part of the stem down to *m* are filled with alcohol. This is the real thermometric part of the instrument; the column of mercury, *m m'*, which occupies the U-shaped part of the tube, merely acts as an index. The tube above *m'* and the lower part of the bulb C are filled with alcohol; the upper part of C contains only alcohol vapour, so as to allow for expansion. As the alcohol in B expands or contracts, the extremities, *m* and *m'*, of the mercury column rise or fall as the case may be, and the extreme point reached in each case is indicated by one end of a light steel index, *i* or *i'* (shown on a larger scale at I). This index is pushed before the mercury column, and is prevented from returning by means of a spring, *s*, which is just strong enough to hold it in its place. The position of the index *i* evidently indicates the minimum temperature reached, and that of *i'* the maximum temperature. When it is required to set the instrument ready for any observation, these indices are brought into contact with the ends *m* and *m'* of the mercurial column by means of a small magnet. This instrument is largely used by gardeners and nurserymen.

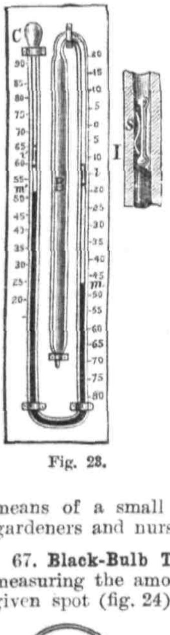

Fig. 23.

67. **Black-Bulb Thermometer.** This is an instrument used for measuring the amount of radiation from the sun that falls on a given spot (fig. 24). It consists of a thermometer whose bulb is

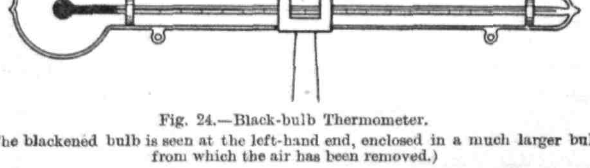
Fig. 24.—Black-bulb Thermometer.

(The blackened bulb is seen at the left-hand end, enclosed in a much larger bulb from which the air has been removed.)

coated with lamp-black. This substance is used because practically all the rays of sunlight that fall on it serve to raise its temperature; the latter, measured by the mercury, gives therefore a good indica-

tion of the intensity of the radiation. As the lamp-black would readily part with some of its heat to the air, and the constant motion of the air would soon carry off a good deal of heat, the black-bulb thermometer is usually enclosed in a glass from which the air has been pumped.

An ordinary thermometer, if placed in direct sunlight, would act in the same way but less perfectly. But what is usually wanted from a thermometer is the temperature of the *air*: that is why thermometers are placed "in the shade," where they are not directly warmed by the sun's rays. The fact that the temperature of the air, shown by an ordinary thermometer in the shade, is much less than that of the lamp-black shown by the black-bulb thermometer, is a striking illustration of the smallness of the heating effect of the solar rays on the air through which they travel. In fact, the warmth of the air is chiefly produced by contact with the earth, not directly by the sun's rays, and in the higher regions of the atmosphere the air is very cold in the brightest sunshine.

68. **Use of Barometers in Forecasting the Weather.** If you examine a "weather chart" issued by the Meteorological Office, or that which appears daily in *The Times* newspaper, you will find upon a map of the British Isles a series of more or less parallel lines called "isobars." The number attached to each line shows the height of the barometer in inches at a given time for all places through which that line passes, supposing they are situated at the sea-level. Thus, from a number of readings taken at the same time by observers far apart, we learn another very important fact about air-pressure—viz. that its amount is never the same even over small areas. Fig. 25 is a copy of a chart for January 12, 1905, from which you will see that, on that date and for the area shown, the pressure was greatest over central France, and least over central Sweden.

Such a chart thus indicates (i) the regions of wind and calm—for the air will naturally move from those of high pressure towards those where it is low; (ii) the relative velocity of the wind—for the closer these regions are together the more rapidly will the air tend to move; and (iii) the direction of the wind. Contrary, however, to what we might expect, the wind does not blow directly across the isobars, but more or less parallel to them. It is found that in our northern hemisphere, if you turn your back to the wind, the low-pressure area will be upon your left hand. [See if this agrees with the chart, in which the direction of the wind is shown by the arrows.] And so by remembering the character of the wind which blows from any particular direction—*i.e* whether it is dry or moist, cold or warm, etc.—the probable weather conditions of any particular locality on the date in question may be roughly determined.

But this is not prediction. To be able to do this, and then only for a short time ahead, it is necessary to follow for some days previously the movements of the areas of low and high pressure, and note the direction they appear to be taking. This requires expert

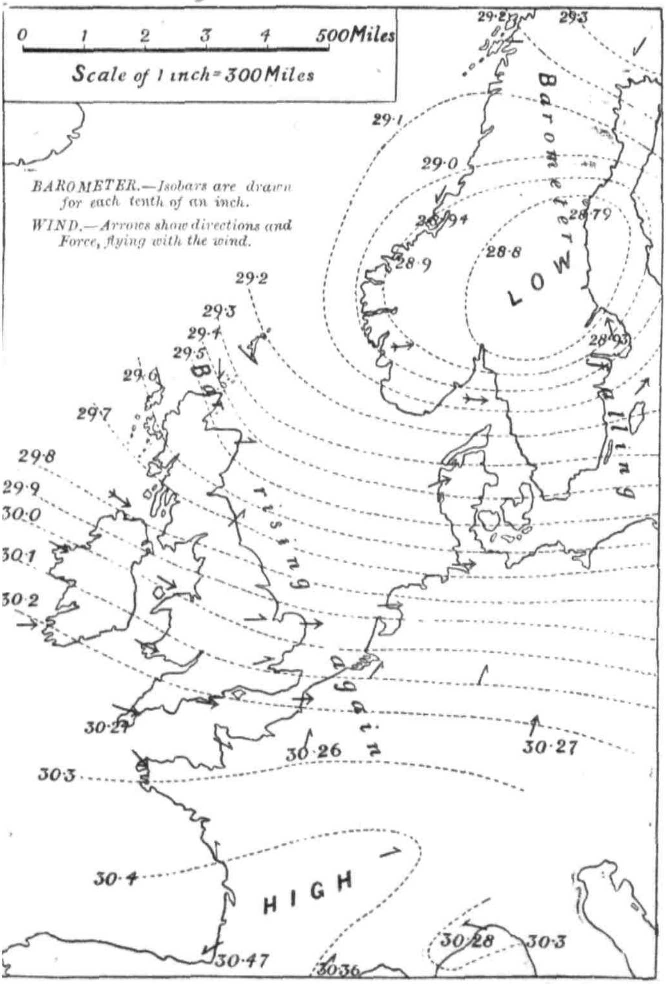

Fig. 25.

[*Inserted by permission of the Controller of His Majesty's Stationery Office.*]

skill and knowledge. What is of more importance to the average individual is to be able to predict the weather for his own locality; and this can be done with some degree of accuracy only by watching carefully the behaviour of his barometer.

The ordinary "weather glass" is a syphon barometer with a mechanical contrivance for magnifying the amount of rise and fall of the mercury. On the exposed surface of the latter floats a glass weight connected with a freely hanging counterpoise by means of a thread passing over a pulley (fig. 17). The latter carries a pointer which plays to and fro over a dial inscribed "Fair," "Change," "Rain," etc. Too much reliance must not be placed upon these interpretations. A little consideration will show that the important points to note are (i) the *direction*, and (ii) the *velocity* of the motion of the pointer. Generally speaking, a *steady* barometer points to a continuation of the weather conditions; a *rising* barometer points, if slow, to fine weather, if rapid, to unsettled weather; a *falling* barometer indicates wet, and if the fall be rapid, wind as well. See how these statements agree with the weather notes in fig. 26. Make readings of the barometer daily and record them on squared paper connecting them to form a curve as shown in fig. 26, which is a portion of an uncorrected record for Cheltenham for 1906. Daily notes on the accompanying weather changes are also given.

69. **Rain-Gauge.** We know that the effects of a short shower are soon over: the roads and fields soon "dry," as we say, though this drying is only partly the result of evaporation, and largely the result of the water flowing away into watercourses and sinking into the earth. If we could prevent the water that falls as rain from either evaporating, flowing off, or sinking in, we should find it accumulating, till in time it was of measurable depth. We could then say that during a given time, say a month or a year, there had been so many centimetres (or inches) of rainfall. This is what is actually done, on a small scale, by the rain-gauge.

An ordinary rain-gauge consists merely of a metal cylinder, into which there fits a metal funnel, and of a glass vessel properly graduated. The object of the funnel is simply to check evaporation. As the actual area whose rainfall is measured is the area of the top of the cylinder, it would be sufficient to measure the depth of the water that accumulated at the bottom; but it is better to pour off the water into a glass vessel of less diameter, for then the height of the water is magnified, and so can be determined more accurately.

In using a rain-gauge, it is important that it should be placed in a thoroughly exposed position, so as not to be sheltered by any upstanding object, such as a house or tree.

70. **Relative Humidity.** Hygrometry deals with all measurements connected with the state of the air as regards the moisture present in it. We speak of the air as being *dry* or *moist* according as we think it contains little or much moisture, but the condition of the air, in relation to dryness or moisture, involves two elements: (1) the

with muslin, which is kept moist by a wick dipping into water (fig. 28). The wet-bulb thermometer gives a lower reading than the other. This is known to be due to the abstraction of heat from the bulb by the evaporating water. But evaporation can proceed only in unsaturated air; and although this is always the case in nature, yet the saturation-point may at certain times be much more nearly approached than at others. Then evaporation will be slower, and the differences in the readings of the thermometers will be small. But these differences, increasing with increased evaporation, are thus seen to vary inversely with the relative humidity. To obtain good comparisons, the instrument should be placed out of draughts. Readings of the wet and dry bulbs were taken daily at 8.45 a.m. and 8.45 p.m. during February and July, and at each of these times the weight of water which had evaporated from an open dish during the preceding 12 hours was recorded. The results are expressed graphically by the curves of fig. 29.

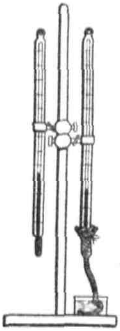

Fig. 28.

The curves (*A*) (*A*) show the average differences of temperature between the wet and dry bulbs in degrees C. (*B*) (*B*) show loss of weight of water during the same times in grams.

The same shallow vessel was used in both observations and its sides were vertical.

The results distinctly show that—

(i) The greater the rate of evaporation, the greater the difference in the reading of the wet and dry bulbs; and

(ii) That greater evaporation goes on in summer than in winter.

Make a wet- and dry-bulb hygrometer; and with it make similar observations over an extended period, and tabulate the results. A small shallow crystallising dish does well to contain the water.

73. **Regnault's Hygrometer.** This consists (fig. 30) of a glass tube *T*, closed below by a thin silver cap *S*. Its mouth is fitted with a cork carrying a thermometer *t* and a piece of tubing *d*, *both passing down nearly to the bottom of the tube.* To use the instrument ether is placed in the tube, and a current of air is drawn through by the aspirator *A*; entering by *d*, the air bubbles through the liquid and enters *A* through the side tube *e* and the vertical tube *V*. This passage of air through the ether in *S* causes rapid evaporation to take place; the temperature of the liquid, therefore, falls, and ultimately the aqueous vapour in the air condenses on the surface of *S*. The temperature is then read. This will be below the dew-point, as no dew is seen till a perceptible quantity has formed. The aspirator is now shut off; the temperature of *S* rises, and when the last trace of dew vanishes the temperature is again read. The mean of the readings is the dew-point.

By regulating the current of air the cooling of the liquid in *S* may be made sufficiently slow to note, with accuracy, the temperature at which the film of moisture commences to form on *S*. This observation is usually further facilitated by having a second tube *S'*, similar to the hygrometer tube, supported on the same stand, in such a position that the appearance of the two silver caps may be easily

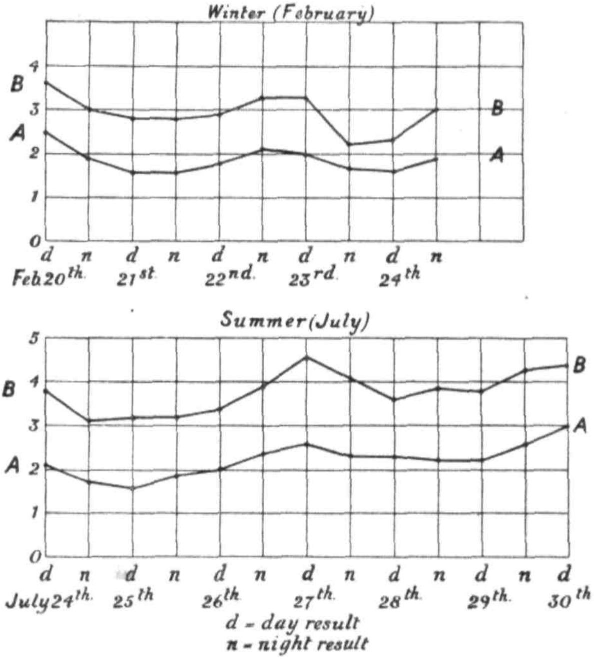

Fig. 29.

contrasted, and the dimness due to the deposition of moisture on *S* more readily detected. *S'* is not, however, an essential part of the instrument: it has no connection with *S* or *V*, and serves only for comparison, as explained above, and to carry a thermometer *t'*, which gives the temperature of the air.

In order to obtain good determinations with any form of dew-point hygrometer, the experiment should be repeated until the tempera-

tures of appearance and disappearance of the film of moisture on the cold surface are very nearly the same, say within ·5° of each other.

The table given below shows the pressure of aqueous vapour at

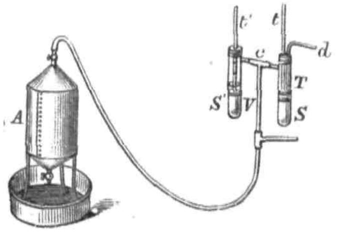

Fig. 30.

various dew-point temperatures. If h denote the relative humidity of the air, f the maximum pressure of aqueous vapour at the dew-point, and F the maximum pressure at the temperature of the air, then—

$$h = \frac{f}{F}.$$

For example, if air, at 15° C., be cooled down to 10° C., before condensation commences, then—

$$h = \frac{f_{10^\circ}}{f_{15}} = \frac{9{\cdot}1}{12{\cdot}7} = 0{\cdot}72\text{; that is, } 72\%.$$

74.—**Table showing Pressure of Water-Vapour** (F) **in mm. and Mass of Water** (M) **in grams contained in 1 cubic metre of Air, with Dew-Point** (T). (*Regnault and Magnus.*)

T	F	M	T	F	M	T	F	M	T	F	M
	mm.	gr.		mm.	gr.		mm.	gr.		mm.	gr.
−10°	2·0	2·1	0°	4·6	4·9	10°	9·1	9·4	20°	17·4	17·2
− 9	2·2	2·4	1	4·9	5·2	11	9·8	10·0	21	18·5	18·2
− 8	2·4	2·7	2	5·3	5·6	12	10·4	10·6	22	19·7	19·3
− 7	2·6	3·0	3	5·7	6·0	13	11·1	11·3	23	20·9	20·4
− 6	2·8	3·2	4	6·1	6·4	14	11·9	12·0	24	22·2	21·5
− 5	3·1	3·5	5	6·5	6·8	15	12·7	12·8	25	23·6	22·9
− 4	3·3	3·8	6	7·0	7·3	16	13·5	13·6	26	25·0	24·2
− 3	3·6	4·1	7	7·5	7·7	17	14·4	14·5	27	26·5	25·6
− 2	3·9	4·4	8	8·0	8·1	18	15·4	15·1	28	28·1	27·0
− 1	4·2	6·4	9	8·5	8·8	19	16·3	16·2	29	29·8	28·6
− 0	4·6	4·9	10	9·1	9·4	20	17·4	17·2	30	31·6	30·1

75. **Is Light required for Germination?** This question is very easy to answer by experiment.

Exp. 96. Place in a dark cupboard or cellar some jars or boxes containing seeds planted in moist sawdust. Compare with seeds of the same kind, planted and watered in the same way, but set in the light.

Exp. 97. A better plan is to keep the two sets of seedlings close together; exclude the light from one lot by covering the jar or small pot in which the seeds are planted by inverting over it a large flower-pot (with the hole corked) or putting it into a tin or wooden box with a few small holes for ventilation. Compare the rate of growth of the two sets of seedlings from day to day, and note any other differences between them.

76. **Light retards Growth.** These experiments will show that light retards the growth of seedlings, since they grow faster in the dark. You will also notice that the darkened seedlings have small pale leaves instead of well-developed green leaves. We shall deal with these differences later.

77. **Conditions necessary for Germination.** If you have carefully carried out the simple experiments on germination, for which directions have been given, you will know what conditions are essential for germination of a seed. The young plant must be alive; the seed must be given *water*, *air*, and sufficient *warmth*. These are essential for the awakening of the young plant from its sleep. We shall see later that for the continued healthy growth of the plant other conditions are necessary, without which the seedling after a time dies.

78. **Respiration causes Waste.** If you read again the parts of this chapter that deal with carbon and carbon dioxide — *e.g.* Art. 56, Exp. 80–3 — you will see on reflection that the germinating seed must lose carbon in its respiration. To measure this loss we must, of course, dry the seeds and seedlings before weighing them. Does this loss occur both in light and in darkness?

Exp. 98. Take about forty beans as nearly alike in size and weight as possible; select four of them as samples, and find their weight after thoroughly drying them on a water- or sand-bath or in a slow oven. Take the dry weight of a seed, found in this way, as the average. Sow half of the seeds in sawdust in a box which is kept in darkness, the other half in a box kept in full light; water both lots about equally. At the end of each week, measure and record the average

80. **Food stored in Bean Seed.** From these simple tests it appears that in addition to carbon the bean seed contains nitrogenous substances and also some mineral matter (ash ingredients). The following table shows the chief classes of food necessary for human beings:

Food.

- Inorganic.
  - Water.
  - Mineral Salts.
- Organic.
  - Proteids or Nitrogenous foods.
  - Non-nitrogenous foods.
    - Fats.
    - Carbohydrates or Sugars and Starches.

The bean seed contains water, mineral salts, proteids, fats, and carbohydrates—that is, all the chief kinds of human foods. A section through a cotyledon, examined with the microscope, shows an outer layer of small cells containing fine-grained protoplasm (living substance, consisting of proteids) and a darker-staining body (nucleus), while the rest of the cells contain protoplasm and nucleus together with numerous small proteid-grains and larger starch-grains, the latter being white glistening bodies. On adding some iodine solution, the starch-grains are seen to turn blue, while the protoplasm and proteid-grains turn brown. The walls of the cells, or closed chambers of which the cotyledon is formed, consist of *cellulose*, a carbohydrate which is not stained by iodine alone, but turns blue when treated with sulphuric acid and then with iodine. The dry Broad Bean seed contains about 60 per cent. of starch, 25 per cent. proteids, 3 per cent. oil, and about 4 per cent. ash ingredients (calcium, magnesium, potassium, sulphur, phosphorus, etc.); the residue consists chiefly of cellulose (in cell-walls) and some silica (in seed-coat).

81. **Carbohydrates.** Starch and sugar both exist abundantly in plants, and are called carbohydrates, because on analysis the proportion by weight of hydrogen to oxygen found united with the carbon is always the same as exists

in water—viz. 1 : 8. It must be clearly understood, however, that they are *not compounds of carbon with water*. Starch is insoluble in cold water, but is easily converted into sugar, which is soluble, by various chemical bodies. Both resist change when exposed to air, and sugar is even used to preserve various foods from decomposition, as jams, crystallised fruits, etc. A *weak solution* of sugar, however, exposed to the air is soon converted into one of alcohol. Other carbohydrates are the celluloses and gums.

Exp. 103. Heat some ordinary dry starch in a test-tube. Note the condensation of water in the upper part of the tube. This proves the presence of *hydrogen* and *oxygen* in starch (since water is composed of these elements). Note also that the starch soon begins to *blacken*, proving that it contains *carbon*, and at the same time dirty white fumes are evolved, having a pungent odour somewhat resembling that of burnt sugar. Apply a light to the mouth of the test-tube—the fumes are *inflammable*; introduce a piece of moist blue litmus paper into it—the litmus becomes red, showing that the fumes are *acid*. Introduce a glass rod, on the end of which is a drop of lime-water, into the test-tube. The lime-water becomes milky, showing that *carbon dioxide* is one of the products of decomposition of starch. This confirms the presence of carbon in starch (since carbon dioxide is a compound of carbon and oxygen).

When all the volatile matter has been driven off, a black glistening residue of *charcoal* remains.

Exp. 104. Shake a very little starch in a test-tube of cold water and boil well; add a few drops of iodine solution: a blue colour is formed. Boil the blue solution, and the blue colour disappears, to return on cooling.

Exp. 105. Boil a little starch with dilute sulphuric acid, and test a few drops of the solution from time to time for (1) starch, as in Exp. 104; and (2) sugar, as in Exp. 106. The reactions of starch are gradually lost, and those of sugar appear instead.

Exp. 106. Examine specimens of cane, grape, fruit, and milk sugars. (1) Taste them: they are all sweet. (2) Boil with a solution of caustic potash: cane sugar does not colour the solution, but the others turn it brown. (3) Add a little Rochelle salt (sodium potassium tartrate), then excess of caustic potash, and finally some copper sulphate solution.* [The object of the Rochelle salt is to prevent the precipitation of cupric hydroxide by the action of potash on

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* This is called Fehling's test. Dissolve 35 grm. of copper sulphate in 200 c.c. of water to make solution A. To make solution B (to be kept in a separate bottle) dissolve 70 grm. of Rochelle salt in 200 c.c. of 10 per cent. caustic potash solution. Use equal volumes of solution A, solution B, and water.

copper sulphate.] Boil: cane sugar only precipitates red cuprous oxide on long boiling, but the others give a precipitate at once. (4) Add a solution of silver nitrate to which excess of ammonia has been added, and warm: the cane sugar only reduces the silver after long boiling; the others do so very soon.

Exp. 107. Boil some cane sugar with dilute sulphuric acid for ten minutes, and test the resultant solution as in Exp. 106; it now gives the same reactions as the other sugars.

These properties of possessing a sweet taste and of turning caustic potash brown and reducing copper sulphate and silver nitrate, either at once or after previous boiling with dilute acids, are characteristic of the sugars.

Exp. 108. Moisten a little starch with a few drops of dilute hydrochloric acid and heat gently in a dish. The sticky mass obtained is *dextrin*, or "*British gum.*" This on boiling for some time becomes malt sugar.

Dextrin gives a brownish colour with iodine solution, whilst sugar gives no colour at all. It is also formed by simply heating starch; it occurs in the crust of bread.

82. **Proteids,** or nitrogenous food-stuffs, composed of carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus, occur in both vegetable and animal tissue, though only plants can build them up from their elements. They form the living substance (protoplasm) found in cells of plants and animals; in decaying, they give off offensive smells. **Albumin** occurs in white of egg, **myosin** in lean meat, **gluten** in flour, **fibrin** in blood, **casein** in milk and cheese, and **legumin** in peas and beans. The first three—albumin, myosin, and gluten—are coagulated by heat.

83. **Wheaten Flour,** made from the grains (seeds) of wheat, makes very convenient material to examine and test for starch and proteids (Exp. 109–119).

Exp. 109. Take a tablespoonful of wheaten flour and enclose it in a piece of muslin. Hold it under a tap of gently running water and work the flour about by constant squeezing. Catch the whitened water as it flows away from the flour. In a little time the water passes off clear. Keep working it for a little longer time, then open the muslin and discover a mass of sticky material. This is gluten, the albuminous constituent of Wheat. Allow the muddy water to settle, then pour off the liquid and keep the sediment. The sediment is starch; it forms a large proportion of the flour.

Exp. 110. Put a bit of gluten about the size of a barley-corn on the end of a mounted needle, and hold it over the flame of a spirit-lamp; it burns. Notice how it turns black a few seconds after it is

held in the flame. Test the charred mass by rubbing it on a piece of clean white paper; it leaves a black mark of charcoal or carbon.

Exp. 111. Mix a little of the gluten with soda-lime, place the mixture in a test-tube, and heat by means of a spirit-lamp. As the gluten decomposes, ammoniacal fumes are given off, thus proving the presence of nitrogen in the gluten.

Exp. 112. Put a little of the gluten into a test-tube containing a weak solution of caustic potash. Shake well. Note that the gluten dissolves.

Exp. 113. Put another bit of gluten into a small quantity of strong nitric acid in a test-tube or watch-glass. Heat. Note the yellow coloration which deepens to orange if ammonia solution be gradually added. Add the ammonia solution very cautiously with a glass tube, as the action between the acid and the alkali is a violent one.

Exp. 114. Place a little of the sticky gluten in a test-tube and warm it. Notice that the heat causes it to solidify. This does not occur with the proteid (legumin) present in Beans and Peas.

Exp. 115. Repeat Exp. 110 and Exp. 111 with starch, and observe that while starch contains carbon, it differs from gluten (and other proteids) in being non-nitrogenous.

Exp. 116. Take a little of the milky liquid from the basin. The milkiness is due to starch granules. Boil it; this makes it go clear. Cool the clear liquid, and add a few drops of solution of iodine. A deep blue colour proves the presence of starch. Note that the blue colour disappears on heating.

Exp. 117. Place some of the milky liquid on a glass slide, cover and examine under the microscope. Observe the roundish disc-like grains. Treat with solution of iodine and note the resulting coloration. It will be seen that the grains are not all the same size, some being relatively very small.

Exp. 118. Mix a small quantity of starch powder with water in a test-tube. Shake. The fluid is milky-looking. Add a solution of potash and again shake. Note the result.

Exp. 119. Place a small quantity of flour in a porcelain dish over the Bunsen flame. It is first turned black, but finally a grey ash is left behind. This is chiefly phosphate of potassium.

84. **Oil and Fat.** Just as some plants store up carbonaceous food for future use in the form of *starch*), others do so as **oil.** This may be seen in various *nuts*—the fruit of the *olive*, which yields "sweet" or "salad" oil; seeds of the *flax* plant, yielding "linseed" oil, etc. The corresponding food store in animals appears as **fat.** Tallow is mainly fat of beef and mutton. An *oil* may be defined as a liquid which when dropped on glazed paper renders it translucent, and

a *fat* as a solid which when melted behaves in a similar manner. Oils and fats are compounds made up of carbon, hydrogen, and oxygen, the oxygen present being insufficient to combine with all the hydrogen and form water. Chemically they are best considered to be compounds of fatty acids with glycerine. Thus palmitin is the fat composed of palmitic acid and glycerine; olein and stearin are fats containing oleic and stearic acids respectively. The ordinary fats in food contain varying proportions of stearin, palmitin, and olein. The greater the quantity of olein present the less solid the fat is. Olein and palmitin may be obtained from plants or animals; stearin from animals only. Most vegetable oils are obtained from seeds, *e.g. mustard, olive, sunflower, linseed, castor oil.* Others are obtained from the stem, *e.g. oil of turpentine*, others from the leaves, *e.g. eucalyptus oil*, and others again from the flowers, *e.g. lavender oil* and *attar of roses.*

We can distinguish two classes of vegetable oils—(1) those which are volatile and are called *ethereal* or *essential* oils; (2) those which are not volatile, and are called *fixed* or *non-volatile* oils.

Exp. 120. Allow drops of oil of turpentine and olive oil to fall on different parts of a sheet of paper. The oil of turpentine soon disappears; the olive oil does not disappear. The former is a volatile oil, the latter a non-volatile oil.

Exp. 121. Remove the coats from dry seeds of Sunflower, Cress, Mustard, Castor Oil; fold the seeds in blotting-paper and crush between two flat stones (or by any other method), and note the greasy stain produced, which dissolves in ether or alcohol.

85. **Milk** is a liquid consisting of emulsified fat, water, proteids, salts, and carbohydrates, and having a specific gravity of 1032 (water being 1000). The proteids are mainly casein and a little albumin; the carbohydrate chiefly present is lactose or milk sugar. The salts include phosphates of calcium, potassium, and magnesium. It is obviously a perfect food, because it is the sole nourishment provided for the young of the higher animals; and, moreover, it will maintain adults in perfect health for an indefinite length of time. With regard to its composition, it is important to notice that it contains representatives of

the four great food-classes—proteids, fats, carbohydrates, and salts, as well as water. The average composition of cow's milk is given below:

Water.	Sugar.	Proteids.	Fats.	Salts.
87	4·5	4	3·8	·7

When milk is allowed to stand, about 10 per cent. of its volume of cream should rise to the top. The cream consists of the greater part of the fat, together with a small amount of the other constituents. By adding rennet or very weak acid to milk it is separated into a solid called the curd, and a clear liquid called whey. The solid consists of coagulated casein with the fat and some of the sugar and salts. The whey contains lactose and salts. When milk is boiled, the albumin is coagulated, and other changes are produced, which cause the milk to possess an altered flavour. The coagulated albumin collects on the top as a kind of skin.

Exp. 122. (*a*) Dilute a small quantity of milk with an equal volume of water; add a few drops of vinegar, or dilute acetic acid, until a slight precipitate is formed. Then warm the liquid gently (do not boil). Filter. The white solid left on the filter paper is mainly **casein.**

(*b*) Boil the clear filtrate from (*a*). Any albumin that may be present will be coagulated. Filter this off.

(*c*) Test the clear filtrate from (*b*) for sugar. To do this, add a few drops of Fehling's solution and boil. If sugar is present, a red precipitate will be produced.

Exp. 123. Test the curd formed in Exp. 122 (*a*) with nitric acid and ammonia; it turns yellow, casein being an albuminous substance.

86. **Eggs.** As the chick is developed from the egg, it is obvious that the egg must contain everything that is required for the construction of the body; but it is not such a perfect food as milk, because an egg is deficient in salts. A hen's egg consists of 70 per cent. of water and 30 per cent. solid matter. Of the solids, the white is mainly albumin; the yolk contains fat, albumin, and phosphates. Eggs form a very valuable article of diet, being rich in proteids and fat.

Exp. 124. Prove the presence of albumin in white of egg, and in the yolk also, by mixing each with a little water and boiling the mixture in a test-tube. Albumin is coagulated by heat.

Exp. 125. Put a small piece of hard-boiled egg on the point of a mounted needle and hold it in the flame of a spirit-lamp for a few seconds. It chars. This proves that it contains carbon.

Exp. 126. Mix a little of the egg-albumin with soda-lime; place it in a test-tube, and heat. Ammoniacal fumes are given off. This proves that the albumin contains nitrogen.

Exp. 127. Take some fresh egg-albumin; add water and mix well. Filter. To a small portion of the filtrate in a test-tube, add a drop of nitric acid. The albumin turns a yellow colour. Carefully add a drop or two of ammonia. The colour deepens. This is a good micro-chemical test for albumin.

87. **Digestion of Reserve Food.** The foods stored up in seeds for the use of the young plant must be insoluble in water, and not able to diffuse through membranes (cell-walls); why? The reserve food in the bean cotyledons must, however, when the seed germinates, travel from cell to cell through the cell-walls in order to reach the places where it is needed (radicle and plumule), and in order to do this the food must be changed into soluble and diffusible substances. The food stored in a seed must, in fact, be *digested* before it can be used by the young root and shoot, and the process of digestion in a plant is essentially the same in an animal. Find out all you can, from books on Physiology, about the digestion of starch, proteids, and fats. In the germinating seed, just as in an animal, starch is converted into sugar, proteids into peptones, oils are emulsified and converted into fatty acids and glycerin (which are further changed into sugars, etc.).

88. **How Starch is digested.** We have seen (Exp. 105) that when dilute acid is added to starch the latter is changed first to dextrin and then to sugar. In our bodies the conversion of starch into sugar is partly effected by saliva (formed by glands which open into the mouth) and partly by the pancreatic juice (secreted into the part of the intestine just beyond the stomach). In both cases, the change of starch into sugar is due to a substance, called a *ferment*, present in the secreted juice. A similar ferment occurs in plants, called *diastase*; the starch-converting ferments of animals get other names, but might be called *animal diastase*, to emphasise their essential similarity. It

is easy to prove that diastase occurs in germinating seeds in which starch is stored. Starch is changed to grape-sugar by being made to unite with water, the action being called *hydrolysis*. This can be brought about, as we have seen, by boiling starch in water for a long time, or more quickly by adding acid to the water.

Exp. 128. Boil a little starch in water and put a little of the cooled paste on the tip of the tongue. After a short time it tastes sweet, showing that some of the starch has been changed to sugar by the diastase (ptyalin) of the saliva.

Exp. 129. Mix a little starch-paste in a test-tube with saliva, warm it to body-temperature by holding the tube in the hand, or placing it in warm water, for a few minutes; then add Fehling's solution, and boil. As a control, test separately for sugar the starch-paste and the saliva before mixing them.

Exp. 130. Add to some starch-paste a small quantity of filtered saliva which has been heated to boiling; apply Fehling's test. No sugar is formed; the diastase in the saliva has been destroyed.

Exp. 131. Make a thick paste with flour and water, and mix with it some extract of malt. Keep the mixture about the same temperature as the body. The malt quickly liquefies the paste. Test for sugar in the liquid by tasting it, and by Fehling's solution. The first step in the process of brewing is to let Barley germinate until the starch is changed to sugar; the grain is then killed by heat, and a watery extract (malt) is made; yeast is then added, by the action of which the sugar is changed largely to alcohol.

Exp. 132. Make thin starch-paste by shaking up a little ordinary starch or flour with boiling water and letting it stand to cool. Get some Pea seedlings in which the radicle has grown out at least an inch; remove the seed-coats, grind the cotyledons up with water, and filter through a funnel with filter-paper or thin blotting-paper. Pour the starch-paste into white saucers, putting a label on each. Leave saucer 1 as it is; into 2 pour a few drops of iodine solution; into 3 pour some of the watery extract from the cotyledons. Set the three saucers in a fairly warm place, and after a time test 1 and 3 with iodine solution. Notice that the starch-paste with the extract in it soon gives only a reddish colour with iodine, and ultimately remains uncoloured by iodine, showing that the starch has disappeared. Taste the liquid in saucer 3, to which the extract was added; the starch has been converted into sugar by a substance (diastase) which has been extracted from the cotyledons (filter, and to clear filtrate apply Fehling's test).

Exp. 133. Take some Wheat-grains which have begun to germinate, and squeeze the brown husk of a grain on to a glass slide. Add a little water, cover, and examine with the high power. Note that

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Exp. 133. Take some Wheat-grains which have begun to germinate, and squeeze the brown husk of a grain on to a glass slide. Add a little water, cover, and examine with the high power. Note that

many of the starch-grains are broken into bits, or show extensive cracks and cavities. Test with iodine.

Exp. 134. Examine in the same way sections of the cotyledons of Bean and Pea seedlings.

Exp. 135. Squeeze the milky contents of about half a dozen sprouting Wheat-grains into a test-tube or watch-glass with a little water, and stir. Filter, add a few drops of Fehling's solution to the clear filtrate, and heat. A brick-red coloration indicates the presence of sugar.

89. **Digestion of Proteids.** Proteids are acted on in the animal body by the gastric juice in the stomach and by the pancreatic juice in the small intestine; the former contains a ferment, pepsin, which acts only in acid solutions, the latter a ferment, trypsin, which acts only in neutral or alkaline solutions (this is the case with the diastase of saliva and of pancreatic juice). The cotyledons of germinating Beans and Peas contain a ferment resembling trypsin, which converts the proteids into soluble substances, including peptones. Peptones differ from other proteids in being very soluble, and are, moreover, **diffusible**—that is, they are able to pass through a membrane from a solution rich in them to a solution poor in them. The process goes further, however, the peptones being converted into simpler substances, just as happens in the pancreatic action on proteids.

Exp. 136. Get a fresh pig's stomach from the butcher's, cut it open, and wash it out. Next scrape off the inner coat with a blunt knife, and mince it up. Put it into a mortar, and rub it up with some ·2 per cent. hydrochloric acid solution. Leave it in a warm place for two hours. Pour off the clear liquid, put it into some very small fragments of hard-boiled white of egg, and keep it at about the temperature of the body. In less than an hour the white of egg (albumin) will probably have disappeared. It has been changed into peptone.

Exp. 137. Heat some of the liquid from Exp. 136, containing peptone, and notice that no clot is formed; peptone is not coagulated by heat.

Exp. 138. Get a fresh pig's sweetbread, chop it up finely, and put it to soak in a 1 per cent. solution of sodium carbonate. Pour off the clear liquid, and use part of it instead of the saliva in Exp. 129. Show that it turns the starch into sugar. Use the other part instead of the gastric juice in Exp. 136, and show that it digests coagulated albumin.

90. **Digestion of Oils**. Both the bile and the pancreatic juice act upon fats. They mainly produce what is called emulsification. This simply consists in breaking up the fat into very tiny globules, which remain suspended in the liquid and do not run together again. If oil is shaken up briskly with water it is broken up into small globules, but these run together again on standing. By first adding a little carbonate of soda to the water, and then shaking up with oil, a much more permanent effect is produced, and this milky fluid may be allowed to stand for some time without any of the oil running together again. The emulsification of fats by the bile and the pancreatic juice is greatly aided by the chemical change that the pancreatic juice causes fats to undergo. It acts upon a small portion of the fat, and changes it into glycerine and a fatty acid. The fatty acid unites with the alkaline salts of sodium that are present and forms a soap,* which greatly increases the power of the pancreatic juice to emulsify fats. This power of changing fats into glycerine and soap (both of which are soluble in water, and can readily pass by diffusion through cell-walls) is due to the presence of a ferment called *lipase* (steapsin) in the pancreatic juice. Lipase also occurs in seeds where the reserve food is oil.

Exp. 139. Pour a few drops of linseed oil into a test-tube, and add a little water (about 1 in. deep). Place your thumb over the end of the test-tube, and shake the contents vigorously. Note the appearance of the mixture, and put the test-tube in the stand for a quarter of an hour. It will then be noticed that the milky appearance has disappeared, and that the oil and the water have separated again into two distinct layers. This is only temporary emulsification.

Exp. 140. Repeat Exp. 139, but this time add a pinch of carbonate of soda to the water before shaking up. The emulsification produced this time is of a much more permanent character.

Exp. 141. Shake up some linseed oil with its own volume of 50 per cent. alcohol (diluted methylated spirit) and test it with litmus papers; it is neutral. Add to the mixture some castor-oil seeds which have just begun to germinate (crush or chop them up), and test again with litmus after a few hours; note the acid reaction due to fatty acids.

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* "Hard" soap is sodium stearate, "soft" soap is potassium stearate (see Art. 84).

Exp. 142. Heat a little glycerine with small pieces of acid potassium sulphate for a few minutes; note the sharp, pungent smell produced. Test some of the liquid from Exp. 141 in the same way: the characteristic smell (of acrolein) shows that glycerine is present. Another test for glycerine is to add a few drops of copper sulphate solution and then potash solution; a deep blue colour is produced, but no precipitate.

91. **How long the Seed's Food lasts.** We shall see later that green plants get their food from two main sources, air and soil. The young plant in a seed has a store of food for its early growth, a store which is sometimes very scanty and sometimes (as in bean and pea) very abundant. We know that tap-water and even rain-water are not pure, but contain dissolved substances, while soil-water or river-water will be much richer in dissolved matter. In order to find out how long the stored food lasts, we should therefore use distilled water, so that we know exactly what the roots have had at their disposal; we may use well-washed sand and water it with distilled water. Seedlings whose roots grow in pure water do not live very long, as a rule, especially if they are kept in darkness, when their dry weight diminishes, and they die after using up the stored food. In the light, however, the seedlings live for a longer time, and increase in dry weight. When the store of food in the seed is very abundant, as in Bean and Pea, the seedlings exposed to light, with roots in distilled water, grow for several months and even produce flowers, though they are small and weakly as compared with seedlings grown in soil. Small seedlings, with scanty food-stores—*e.g.* Mustard—live only a few weeks when exposed to light and supplied with distilled water, and only for a few days when kept in darkness.

Exp. 143. Deprive Beans and Peas of one or both cotyledons, and observe the result. Remove the cotyledons, in different cases, just after the seed has soaked, after the root has grown 2 in. long, after the plumule has grown 2 in. long.

Exp. 144. Grow various seeds in jars containing distilled water, fixing them either into holes in muslin or flannel, or into split or bored corks; fill up the water as required, but always use distilled water. Keep some of them in darkness, expose others to the light, and compare their growth and their increase or decrease in dry weight. Another method is to let the roots grow into sand that has been washed thoroughly with tap-water and then with distilled water, using the latter for watering afterwards.

92. **How Food is transported.** The soluble foods produced by the action of ferments are able to diffuse in solution through the cell-walls, and to travel in this way to the places where they are needed, to supply material and energy for the growth of the young root and shoot. It is easy in most seedlings to trace the passage of the digested foods, especially in the case of sugar, because whenever the sugar accumulates in a cell some of it is changed back to starch for a time.

Exp. 145. In seedlings of Bean, Pea, and other plants you are growing, note that the radicle and plumule of the ungerminated seed as a rule contain no starch, but that after germination has begun, starch appears in the young root and shoot (cut these parts in halves longitudinally, and apply iodine solution to the cut surfaces).

93. **Energy furnished by Foods.** The amount of energy supplied by a food may be found by measuring the heat produced by burning it, and it is therefore called the *fuel value.* The fuel value of carbohydrates and proteids is about the same, that of fats is more than twice as great. Since in plants, as in animals, the energy is obtained from the food by oxidation (= burning), and since carbon is the principal substance burned, setting free carbon dioxide, we can by measuring the carbon dioxide given off calculate the amount of energy set free from the carbon of the food. Burning 1 grm. of carbon sets free enough energy to raise 8 kg. (= about 8 quarts) of water from 0° to 1° C., and about 2 litres (about 2 quarts) of carbon dioxide are given off. If all this energy were used in mechanical work, it would suffice to raise 3,400 kg. weight through 1 m. (*i.e.* to raise more than 3 tons a yard high). The energy is used up by the plant in the form of heat and of chemical work, in addition to mechanical work.

94. **Emergence of Seedlings from the Soil.** You will have noticed the way in which the plumule of the Bean protects the young leaves from injury by bending backwards at the tip as its pushes its way upwards. Seedlings can grow through hard and stiff soil, and in doing this the plumule must exert considerable force. The plumule of a Broad Bean seedling can push upwards with a force of over a

pound, and since its diameter behind the hooked part is about one-eighth of an inch, the force exerted = 80 lb. per square inch. From the fact that the cotyledons of a Broad Bean of average size contain altogether over a gram of carbon, it is easy to see that the seedling can get a large amount of energy by using the stored food.

Exp. 146. Plant some Beans about 3 in. deep, and pack stiff clayey soil (or plasticine) firmly above them. Watch them to see whether they emerge at the sides or whether they push the whole mass of clay upwards.

Exp. 147. Invert a short test-tube over a bean seedling with a plumule about 3 in. long, then place over this a vertical glass tube open at both ends, inside which the test-tube can slide freely, and clamp this tube to a support. Into the upper end of the open tube place a second test-tube containing mercury or shot. Mark with a paper strip the level of the top of the plumule, and see what weight of mercury or shot is required to prevent the plumule from continuing to grow upwards. Another method is to use a spring inside a closed tube in place of the mercury or shot; measure how much the force of the plumule, pushing up its tube, compresses the spring, then find what weight is needed to compress it to the same extent.

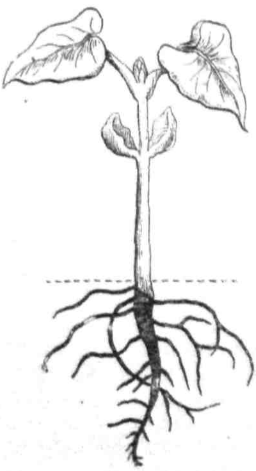
Fig. 32.—Seedling of Dwarf French Bean.

95. **Other Seeds of the Bean Family.** Other seeds should now be examined and germinated for comparison with the Broad Bean. Examine dry and soaked seeds of the following other plants belonging to the Bean Family: Kidney (French) Bean, Scarlet Runner, Eating Pea, Sweet Pea, Lupin, Laburnum (poisonous), Gorse. In Kidney and Runner Beans the micropyle is very conspicuous by its raised margin, the wrinkling of the coat when the seed is soaking is very marked, the plumule bears two very distinct leaves whose veins are easily seen. In the Pea, the transparency of the coat makes it easy to observe that the scar, micropyle, and radicle all lie in

the same line. In each case, make sketches to correspond and compare with those made in the case of the Broad Bean. In germination, most of these seeds differ from the Broad Bean in the fact that the cotyledons are carried above the soil by the elongation of the part of the axis (hypocotyl) which lies just below the cotyledons (fig. 32). In Broad Bean and Pea, this region does not elongate, hence the cotyledons remain below ground.

96. **Other Seeds and Seedlings.** Study as many kinds of seeds as possible. Soak, dissect (remove coat, or cut sections), examine with lens, and compare them with seeds already studied. Test cut surfaces with (1) iodine solution for starch (blue) and proteids (brown); (2) a drop of strong sugar-solution, followed by a drop of strong sulphuric acid (bright red colour = proteids); (3) nitric acid and ammonia (yellow colour = proteids). Practically all seeds contain proteids, together with either starch or oils. Try the tests already given for oils (Art. 84, Exp. 120, 121). If you have a microscope, cut thin sections and examine them mounted in water, then add a drop of iodine solution; oils may be seen as bright-looking drops in the protoplasm, in sections cut with a dry razor and mounted in olive oil. Sow the seeds in moist sawdust or soil, note the temperature required (or most favourable) for germination in each case; examine and sketch the seedlings from time to time. In moistened seeds of Linseed and Cress, observe the jelly formed by swelling of the gummy seed-coat. Small seeds—*e.g.* cress, mustard, wheat—are most conveniently grown on muslin or flannel stretched over a tumbler filled with water.

Exp. 148. *Seeds with Food in Cotyledons.* Examine seeds and seedlings of Sunflower (fig. 33), Acorn, Horse-Chestnut, Almond, Vegetable Marrow, Apple, Sycamore, Linseed, Cress, Mustard (fig. 34). In nearly all cases, the cotyledons are carried up into the air by the lengthening of the axis between radicle and cotyledons. In Horse-Chestnut the large cotyledons are partly fused together; notice that on germination the young stem and root are pushed out of the seed by the lengthening of the cotyledon-stalks. In Vegetable Marrow notice the method by which the seedling gets its cotyledons out of the cavity enclosed by the rigid walls of the flat seed; an outgrowth ("peg") is formed to hold down the lower half of the seed-coat

against the soil, while the expanding upper part of the young plant raises the upper half of the coat and thus grows upwards. In Sycamore, notice how the long cotyledons are wrapped up in the seed; in cress the cotyledons are three-lobed, in mustard two-lobed.

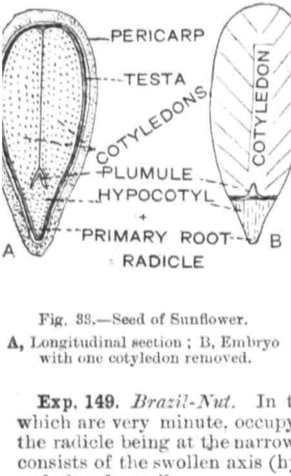

Fig. 33.—Seed of Sunflower.
A, Longitudinal section; B, Embryo with one cotyledon removed.

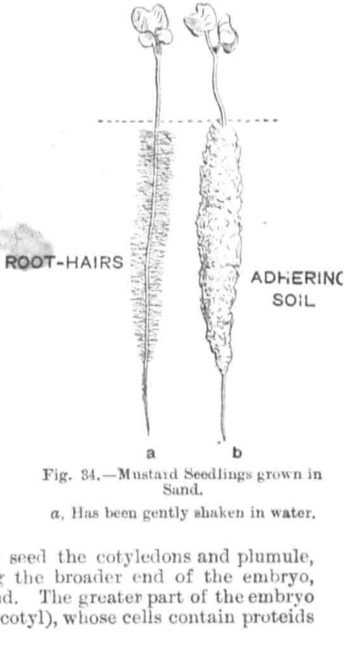

Fig. 34.—Mustard Seedlings grown in Sand.
a, Has been gently shaken in water.

Exp. 149. *Brazil-Nut.* In this seed the cotyledons and plumule, which are very minute, occupying the broader end of the embryo, the radicle being at the narrow end. The greater part of the embryo consists of the swollen axis (hypocotyl), whose cells contain proteids and abundant oil.

97. **Endospermic Seeds.** In many seeds, the stored food is not contained in any part of the young plant itself, as in all the seeds so far considered, but in a special part of the seed called the endosperm, which lies within the seed-coat but outside of the young plant (embryo). In some cases the endosperm completely surrounds the embryo (*e.g.* Castor oil, fig. 35; Ash). In a few cases the embryo and endosperm are sharply separated by a plane drawn across the seed—that is, the embryo touches the endosperm but is

not surrounded by it (*e.g.* Wheat, Maize). Unfortunately the old term "albumen" is often used instead of endosperm, and this sometimes leads to confusion. Endospermic or "albuminous" seeds are seeds whose food is stored in a part outside of the embryo, and this food may be chiefly starch (*e.g.* Maize) or largely oil (*e.g.* Castor oil), or cellulose in the form of much-thickened cell walls (*e.g.* Date and other Palms). The term "albuminous" as applied to seeds does not imply the presence of proteids similar to egg-albumin.

Exp. 150. *Castor Oil.* Notice the spongy mass covering one end of the seed; the hard seed-coat, the oily endosperm, the embryo in the middle of the endosperm, with thin cotyledons pressed together (try to find radicle and plumule); cut longitudinal and transverse sections (fig. 35). The spongy mass (aril) soaks up water; prove by placing seeds in hot water that this mass lies close to the micropyle.

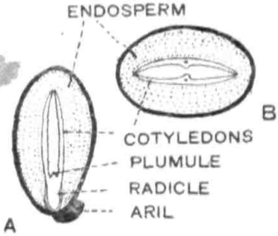

Fig. 35.—Seed of Castor Oil.

A, Longitudinal section; B, Transverse. The dark outline represents the seed-coat.

Exp. 151. *Ash.* Steep the fruits ("keys") of Ash-tree in water, then cut open the fruit-cavity and notice the flat seed suspended at the end of a long stalk which runs along one edge of the seed. Slice away one of the flat sides of the seed and expose the straight embryo, lying in the midst of the horny tissue (endosperm) filled with reserve food.

Exp. 152. *Wheat Grain.* In soaked grains of Wheat, note the deep furrow running along one side; on the opposite side note at one end a small projection (embryo), and at the other end a tuft of hairs (the remains of the stigma). With the needle remove the coat of the grain over the projection, so as to see the radicle and plumule, behind which lies the shield-like cotyledon. With the needle remove the embryo from the rest of the grain, noting the smooth surface of the cotyledon. Make a longitudinal section of the grain, cutting down the groove, and sketch what you see with the lens. Touch the cut surface with iodine solution; the endosperm turns blue, since it contains starch, while the embryo turns brown. Sketch, showing the embryo (radicle, plumule, cotyledon) and the food-containing tissue (endosperm). With a needle raise the radicle and plumule from the cotyledon; in the plumule note the young leaves, which can be separated by using the needle. In thin sections (transverse and longitudinal) of the grain, examined

with the microscope, note the layer of cells containing proteid-grains, which lies on the surface of the endosperm, just within the coat of the grain.

Exp. 153. *The Wheat Seedling.* Take a sprouted grain of wheat showing the first foliage leaf, and study—(1) *The root system.*—Note (*a*) the absence of a main or tap root and (*b*) the three, four, or more secondary or adventitious roots springing from the base of the plumule (the embryonic root or radicle never lengthens, but it freely gives rise to lateral branches). Examine the bases of the roots by means of a lens, and observe in each case the minute sheath out of which the root appears to grow; this sheath is produced by the newly formed root bursting through the tissue of the parent axis. (2) *The shoot system.*—Observe the green tubular sheath through the burst apex of which the first foliage leaf has made its appearance. Compare this with earlier stages of germination, especially noting that at first the sheath is closed at the tip; that for some time—certainly for so long as it remains under the soil—it grows at the same rate as the oldest leaf of the enclosed bud, but that sooner or later it gets burst by the rapidly elongating foliage leaf after the tip of the cone is carried well out into the air.

Make a longitudinal section of the grain and the young shoot, letting the plane of section pass through the groove, and taking care as nearly as possible to bisect the central axis of the embryo. Observe that the "flour" or endosperm of the grain, especially in the neighbourhood of the developing plantlet, is reduced to a pulp, and that so far as the bulk of the endosperm is concerned it has suffered considerable loss. The loss becomes more apparent as the moisture in the pulp evaporates on exposure to the air. The cotyledon acts as a digesting and absorbing organ; it produces the ferment that changes the starch stored in the endosperm-cells into sugar, which then must pass in solution through the shield-like cotyledon to reach the radicle and plumule.

Exp. 154. Examine in the same way some grains of Maize, Barley, Oats, and sketch (1) the external features, showing the white patch (embryo) on one side of the seed, (2) the parts of the embryo seen on removing the covering of the grain from this white patch, (3) the parts seen in a longitudinal section passing through the embryo. Place a few drops of iodine solution on the cut surface, and notice that the endosperm contains abundant starch (shown by the dark purple or almost black coloration), while the embryo only gives a brown colour with iodine (test for protoplasm). Peel off the coat from a grain of Maize which has been soaked for about a week, and after recognising the plumule and radicle, remove the endosperm from the embryo, so as to see the shape of the cotyledon or scutellum.

Exp. 155. Examine a Date seed (*i.e.* the "stone"). Notice the deep groove along one side. Scrape the surface on the other side to see the small embryo embedded in the stone (endosperm).

Cut the stone across at this point, and test the cut surface with iodine solution; then dip the stone in dilute sulphuric acid and apply iodine (test for cellulose). Plant some Date stones in damp sawdust or soil, set in a warm place (a heated greenhouse, if possible), and sketch stages in their germination. Open the stone in some of the seedlings, and then notice the softening of the stone and the extent to which the cotyledon has grown inside it. In Date seedlings of different ages, notice in sections of the stone, stained with iodine and sulphuric acid, that the cell-walls become thinner, and that starch grains are formed in the young root and shoot, in darkness as well as in light.

Exp. 156. *Onion Seedling.* Examine a seedling of Onion before the embryo has finally withdrawn its cotyledon from the seed. In carefully uprooted plantlets observe (*a*) the long slender root, (*b*) the slight swelling at the base of the root marking the position of the relatively short stem from which arises (*c*) the long, hollow seed-leaf sharply bent at mid-length, and with its tip still within the testa of the now all but empty seed. Most carefully remove the testa and observe the colourless end of cotyledon coiled like a watch-spring as it lies within the seed. During the germination period the cotyledon absorbed the food from the endosperm and passed it on to the growing parts. In older specimens observe how the air-exposed tips of the cotyledons wither; also note the formation of secondary roots from the base of the tiny stem. Slit open the hollow leaf-sheath at its base and discover the delicate pale-green plumule within. In still older specimens the plumule itself has split the sheath as a result of its growth and development.

Exp. 157. *Pine Seedling.* In a Pine seed notice the thin wing for wind-dispersal. Dissect the seed and notice the embryo (consisting of radicle, hypocotyl, numerous cotyledons in a circle around the plumule) surrounded by endosperm. Sketch the stages in germination.

98. **The Uses of Cotyledons.** From the seedlings you have studied, you will observe that the cotyledons, or first-formed leaves of the young plant, have different functions or uses in different plants. They are always concerned with the feeding of the young root and shoot, but they carry out this duty in different ways. When the seed contains no food stored outside of the young plant, the cotyledons usually contain food. In a few plants—*e.g.* Broad Bean, Pea—the cotyledons are food-stores and nothing more; they remain below the ground, and simply yield up the food to the growing root and shoot, and are termed "hypogeal" (= below ground). In most non-endospermic plants, however, the cotyledons are carried up into the air

and become green, and like all green leaves *manufacture* food (Ch. IV.); even in these cases, where the cotyledons are "epigeal" (= above ground), they contain more or less food, though the amount is often scanty—*e.g.* Cress, Mustard—and they have a double function, first supplying stored food and then making fresh supplies. In seeds whose food is stored outside of the embryo, the cotyledons either remain within the seed and act as digesting and absorbing organs, as in Wheat, Maize, Date; or they first digest and absorb the food-store in the endosperm, and then emerge from the seed and become the first green leaves of the plant (Castor Oil, Ash, Onion, Pine).

Plants like Cress, Pea, Ash, etc., the embryos of which possess two seed-leaves, are classed under the name *Dicotyledons*, while Onion and Wheat represent the class *Monocotyledons*, as their embryos have only one seed-leaf or cotyledon. Other seeds ought to be collected and examined, care being taken to distinguish between true seeds and seed-like fruits (Ch. VII.).

Make lists of the various seeds you have examined, arranging them according to (1) the presence or absence of endosperm; (2) the number of cotyledons in the embryo; (3) the hypogeal or epigeal character of the cotyledons; and (4) the nature of the reserve food-substances.

QUESTIONS ON CHAPTER II.

1. How can you show that water is essential for the germination of a seed? Why is the young plant in a seed said to be "dormant"?
2. Give the results of experiments you have made as to the volume of water which a Broad Bean seed can absorb as compared with its own volume.
3. What relation exists between (*a*) inches and centimetres, (*b*) ounces and grams, (*c*) pints and litres?
4. What is meant by (*a*) boiling-point, (*b*) freezing-point? How would you convert thermometer-readings from degrees Centigrade into degrees Fahrenheit, and *vice versa*?
5. What is meant by (*a*) "diffusion of liquids," (*b*) "osmosis"?
6. What is meant by "capillary attraction"? Why does water rise higher in a narrow tube than in a wider one?
7. What is meant by (*a*) "specific heat," (*b*) "latent heat"? What is the importance to plant-life of the fact that water has high specific and latent heats?

8. How could you prove, by simple experiments, that air is necessary for germination?

9. How could you prove by experiments that air has weight and that it exerts pressure? Explain the construction of a barometer.

10. What are the effects of changes of pressure and of temperature on the volume of air? How are winds caused?

11. State the composition of air, and the chief properties of its two main constituents.

12. How could you detect the presence of (*a*) water vapour, (*b*) carbon dioxide, in the air?

13. How could you prove that a germinating seed respires (breathes), just as a living animal or a human being does?

14. How could you prove that germination does not occur in the absence of oxygen?

15. Why do seedlings grow badly in soil that is too liberally watered? How could you measure and compare the amount of air in different samples of soil?

16. Why should seeds not be planted very deep, nor merely laid on the surface of the soil?

17. How could you prove that warmth is required for germination, and how could you find, roughly, the best (optimum) temperature for germination in the case of some particular plant? What is meant by (*a*) the minimum, (*b*) the maximum, germination-temperature of a plant?

18. In what different ways is the temperature of the soil influenced?

19. Explain the construction of a Maximum and Minimum Thermometer. Why is a thermometer of this kind often used by nurserymen?

20. Explain the construction of a Black-bulb Thermometer. What is its advantage over an ordinary mercury or alcohol thermometer?

21. What are the important points to attend to in taking barometer-readings, with reference to the weather?

22. What is meant by "relative humidity"? How does the use of a Wet- and Dry-bulb instrument enable us to form a rough idea of the changes in humidity of the air?

23. What are the effects of darkness and of light on the germination of seeds?

24. How could you prove that a germinating seed loses in weight when grown in darkness, that the loss is due largely to the oxidation (or burning) of carbon, and that the cotyledons contain carbon?

25. Compare the food stored in a bean seed with that supplied to young birds in eggs and to young mammals in milk.

26. What is a carbohydrate? Mention the chief carbohydrates, stating how they are distinguished from each other.

27. What is a proteid? How do proteids differ from carbohydrates? By what simple tests could you detect the presence of a proteid?

28. How are oils and fats distinguished from carbohydrates and proteids?

29. How are the reserve food-substances present in a seed made available for the nourishment of the young plant?

30. What is meant by digestion? How are starch, proteids, and oils digested? To what extent are the processes of digestion similar in plants and animals?

31. How could you measure roughly the work done by a seedling in emerging from the soil? Where does the necessary energy come from?

32. What is the usual appearance of the top of the shoot of a young seedling, and what is the advantage of this? How do seedlings of Maize and Wheat differ from most other seedlings in this respect, and how do they emerge from the soil?

33. What is the difference in structure between endospermic ("albuminous") and non-endospermic ("ex-albuminous") seeds? Show that both kinds of seeds may contain the same kinds of food, and explain why the old terms "albuminous" and "ex-albuminous" often lead students into wrong ideas about seeds.

34. Describe, with sketches, the seed, the mode of germination, and the seedling of the following plants: Pea, Kidney Bean or Scarlet Runner, Oak, Ash, Wheat, Maize, Cress, Linseed, Sycamore, Onion, Cucumber or Vegetable Marrow, Sunflower, Date, Pine, Horse-Chestnut, Castor-oil Plant, Mustard.

35. Write an essay on the uses, and the behaviour during germination, of the cotyledons in the various seeds whose germination you have watched.

36. Enumerate the chief reserve materials of food which are stored in the seeds of plants. Give an example of each, and explain how the embryo or seedling is enabled to utilise the food.

37. Explain why it is that certain seeds, for example, Peas and Beans, split readily when the testa is removed. Name as many other such seeds as you can, and describe in some detail the germination of any one of them.

38. Suppose you had two flourishing seedlings of the same size, and you grew one in the dark and the other in the light. How would each differ from its original weight in the course of a few weeks? If one of them had gained considerably, how would you demonstrate exactly to what the increased weight was due? What other differences would you notice between them?

39. What are the chief points you would emphasise in a lesson on the germination of seeds? What material would you select for the practical work of the class?

40. What is respiration, and how is it affected (*a*) by heat, (*b*) by light, (*c*) by increased rapidity of growth?

Two lots of Peas, one of which had been soaked in water at 100° C., the other in water at 15° C., were passed up into the vacua at the tops of two parallel tubes of mercury. How would the height of the mercury column be affected in each case? Would the after-addition of caustic potash solution make any difference to the height of the columns?

CHAPTER III.

ROOTS AND THEIR WORK.

REFER to the parts of Ch. I. in which the root of the Broad Bean is dealt with, go over the observations you have made on the roots of seedlings which you have grown, and examine the roots of as many plants as possible, wild and cultivated, pulling or digging them up and examining them as directed in Ch. I. for the root of Broad Bean. What characters do nearly all roots appear to possess in common, from your own observations on roots of various plants? What do you think are the chief uses, or functions, of roots? How could you test your ideas on this subject by simple experiments? Try any methods that occur to you, before going further.

Exp. 158. In a bean seedling grown in sawdust or soil, cut across the main root about an inch below the surface; the plant falls over. Support the plant by tying it to a stick, and keep the soil or sawdust moist around the cut place; notice the adventitious roots formed from the axis above the cut.

Exp. 159. Repeat Exp. 158 with another seedling, planted by itself in a pot or box, but after tying it to a stick, allow it to remain *unwatered*. What changes does it show, from day to day, in the colour, shape, and position of the leaves, and in any other respects? How would you describe these changes, and what ultimately becomes of the shoot? For comparison, allow some *uninjured* seedlings to remain unwatered; do they show the same changes? What do these simple observations prove as to the work of the root?

Exp. 160. Fix a seedling with its root dipping into water in which some carmine or vermilion has been shaken up vigorously. After an hour or two, cut across the root a short distance above the surface of the coloured liquid. Has any of the colouring-matter (which consists of grains suspended in the water) entered the root?

Exp. 161. Fix a seedling with its root dipping into red ink (colouring-matter in *solution*), and after a time (try several seedlings, and give them different lengths of time) cut across the root, to see how far upwards the colour has spread, and in what part of the root it travels. Also cut across the *stems* of seedlings that have been in red ink for a day or two, and notice the red-stained bundles; how does the liquid travel in the *leaves*?

99. **General Characters.** We have already seen that roots differ from stems in having a root-cap and root-hairs. There are various other differences, but hardly any of these are absolutely constant. Roots do not as a rule bear leaves or buds, but some plants—*e.g.* Hawthorn, Poplar—sometimes bear buds on their roots. Roots generally grow in the ground, but so also do many stems, and in some cases roots are produced above ground—*e.g.* in Ivy. The root may be defined as that member of a plant which tends to turn downwards, away from light and towards water; which, as an almost invariable rule, bears neither leaves nor buds; and which usually has at the apex a protective cap of tissue called the **root-cap.** The internal structure and development, also, are characteristic. It is by consideration of these characters that true roots can be distinguished from root-like stems.

100. **Tap and Adventitious Roots.** As already explained, the terminal portion of the radicle is the embryonic or primary root. In the majority of dicotyledons the primary root, at germination, elongates, grows down into the soil, branches, and forms the root-system of the plant. Little prominences appear upon the surface of the radicle. These rupture, and from each a small *secondary* root makes its way to the exterior. When a secondary root has attained a certain length, it may branch again, and in this way a large branched root-system is formed. As the main root elongates new secondary roots continually appear behind the apex, the older ones being farther behind and the younger ones nearer to the apex. This is known as a tap-root system, the main parent-root being called a tap-root and its branches secondary roots. When a root arises from some other part of the plant (generally the stem), it is said to be adventitious. Adventitious roots are common in dicotyledonous plants, more especially in those with rhizomes, runners, trailing stems, etc. In monocotyledons, in nearly all cases the roots are adventitious. In this group the primary root elongates only very slightly at germination, or not at all, and adventitious roots are developed from the base of the stem.

When Maize germinates, the radicle appears first, and at once bends downwards. The radicle does not, however, form a large tap-root giving rise to the entire root-system, but instead remains thin and fibrous, and may in some cases hardly develop at all. The secondary roots are for the most part *adventitious* in origin—that is, they arise from the stem at the bases of the lower leaves. They sometimes attain a length of several feet and may branch to a certain extent, but remain comparatively thin and retain the "fibrous" appearance characteristic of the root-system of monocotyledons.

Adventitious roots are usually slender and fibrous, but nevertheless they may penetrate to a considerable depth, those of Barley being often more than a yard long, and those of the Maize plant even longer.

101. **Contractile Roots.** In many cases the roots are "contractile," and after becoming buried in the soil they shorten, and so draw the base of the stem into the ground and fix it more firmly, becoming wrinkled as the result of the shortening. They may even draw the stem below the surface and cause it to become subterranean, sending up leaves and flowers above ground each year, but not appearing itself. This occurs in the seedlings of many plants, especially in monocotyledons that develop bulbs, corms, or rhizomes, and in the full-grown roots of many other plants that grow with short stems or with stems that remain below ground, *e.g.* Carrot, Plantain. The branches of some Brambles grow out at the ends into long trailers with small leaves; the tips of these branches produce roots on reaching the soil, and by the contraction of these roots the tip is drawn below the surface.

102. **Mode of Life of Roots.** The mere fact that the root buries itself in the soil is enough to account for some of its distinctive characters. Thus it usually has no green matter, and no pores through which rapid exchanges can take place between the air inside the plant and the outer air; these negative features are partly due to the fact that the root is not exposed to light and air. The root

obtains its oxygen (required by all living parts of the plants) dissolved in the water which it absorbs from the soil. Plants grown in swampy and badly aerated soils usually provide their subterranean parts with oxygen by special means. Thus the roots of the Water-Lily, which grow in the mud at the bottom of ponds, have large air spaces, or canals, which communicate with others in the stem and leaves, so that currents of air charged with oxygen easily pass in by the pores on the floating leaves, and thence to the farthest extremities of the roots.

103. **Functions of Roots.** The functions of an ordinary root—(*a*) the fixation of the plant, (*b*) the absorption of nutritive solutions from the soil—may be carried on in many different ways, according to the nature of the soil or the needs of the plant. We find also that roots may take on special functions. They may function as store-places of nourishment, or as climbing organs. Roots are very commonly influenced by the soil or substratum on which they grow. It is well known that in a dry soil they are usually tougher and more fibrous, whereas under moister conditions they may become much more succulent. Many plants have a natural tendency to form swollen succulent roots, which usually serve for the storage of reserve food-materials.

104. **"Surface-Feeders" and "Deep-Feeders."** Even when the radicle persists as a tap-root, it does not always attain so great a relative length as in the Bean. The tap-root sometimes (*e.g.* in Pines and Poplars) remains short, and the secondary roots grow out horizontally close to the surface. Plants with a flat root-system of this kind are said to be "surface-feeders," and they often live side by side with "deep-feeders" (plants with long tap-root) without the root-systems overlapping; this is well seen in a forest or wood and its undergrowth.

105. **How Roots enter the Soil.** You have seen that the radicle end of the axis is the first part of the young plant to emerge from the seed, and that on emerging it grows downwards, in whatever position the seed has been

placed. Have you tried the effect of moving the seed at this stage, and then turning it over each time the radicle has curved so as to be directed downwards? Have you noticed how, if a seed is laid on firm soil, root-hairs grow out and fix the radicle to the soil so that it can push its tip down with greater force? Have you noticed how the lighter kinds of seeds are often raised up or turned right over by the struggles of the radicle to bore into the soil?

Exp. 162. The downward force which the root is capable of exerting may be roughly measured by causing it to push a cork float downwards into water. Cut a slit in a cork so that it can be firmly fixed to the rim of a tall, narrow jar or a large test-tube, and to this cork pin a bean seedling (with a radicle about 2 in. long) so that its radicle projects into the mouth of the tube. Then place in the tube a number of corks, one above another, of such size that they can move freely inside the tube; the row of corks should be about half as long as the tube. In the uppermost cork make a cavity for the radicle to press downwards against, and pour some water into the tube so that the radicle fits into this cavity. Place a vertical strip of paper on the tube, on which to mark the position of the lowest cork from day to day, and put some wet cotton-wool or blotting paper over the seedling to keep it moist. Each day pour a little more water into the tube (which should be fixed in the vertical position), and thus increase the resistance against which the radicle has to push downwards. When the radicle seems unable to push the chain of corks any farther down, mark the position of the bottom of the lowest cork, then take the seedling out and find what weight (*e.g.* of shot in a test-tube) is required to depress the corks to the same mark. By finding the diameter, and from this the area, of the radicle just above the tip, you can calculate the pressure of the down-growing root in grams or ounces per square centimetre or square inch.

Exp. 163 (*another method*). Fix a young bean-seedling so that its radicle grows in a small tube filled with moist soil or sawdust, and place this tube within a larger one containing a spring. The radicle grows downwards with a force equal to over 300 grm. (about 11 oz.); measure the diameter of the bean-radicle and calculate the force it exerts per square centimetre or square inch.

Exp. 164. We have used mercury in various experiments, and know that it is a very heavy liquid ($13\frac{1}{2}$ times heavier than water). Fix a seedling (bean, pea, etc., should be tried) to the side of a small dish containing mercury with a layer of water above it, and see whether the root will grow down into the mercury.

106. **Geotropism.** It has previously been mentioned that the radicle grows downwards into the soil, and this occurs in whatever position the seed may be placed. If the young root is placed horizontally, it soon begins to bend downwards, the curvature taking place just behind the growing apex. This curvature is soon rendered permanent by the growth and hardening of the tissues affected, but a new terminal straight portion of the root is soon formed as growth continues, and if this be again laid horizontally a downward curvature is produced as before. This curvature is due to the fact that gravity, the attractive force which the earth exerts on all bodies, acts as a stimulus upon the protoplasm at the apex of the root, and causes the growing region to bend towards the centre of the earth. That it is not the action of the *soil* which causes the root to grow downwards is readily shown, either by growing seedlings in moist air, or by planting beans in a pot which is then turned upside-down, for the young radicles still grow downwards, and in the latter case appear on the surface of the soil in the pot.

The primary root may therefore be said to be *geotropic* (turning towards the earth), but the lateral roots usually exhibit a tendency to grow more or less horizontally, that is, they prefer to place themselves transversely to the direction of the force (gravity) acting upon them. They are also influenced by the moistness and character of the soil, being attracted towards, and branching more freely in, those portions of the soil where nutriment and moisture are more abundant. These are all features of obvious utility, for each seed, however it may fall upon the soil, has a chance of attaching itself by its downwardly growing root, and the root-system seeks out those regions of the soil where it can absorb most water and food-material.

Exp. 165. Grow bean or pea seedlings in your box with a sloping glass front. When the side-roots (secondary roots) have grown out, mark on the glass the positions of a few of these, also of the main root; note especially the position of the *tip* of each root. Then tilt the box up at an angle of about 45°, and notice how main root and side roots change their direction of growth.

Exp. 166. Get a test-tube with a cork, and to the cork pin a pea seedling with a straight radicle 2 in. long; put a strip of blotting

paper in the tube, and run in water to soak it. Fix the seedling in the tube with its radicle pointing to the closed end, and keep the tube in a vertical position, with the corked end uppermost.

Exp. 167. Fix a similar seedling in a tube, but keep the tube inverted, so that the radicle points vertically upwards.

Exp. 168. Get a similar seedling and tube, but with a razor or sharp knife cut off the extreme tip of the radicle, and keep the tube in the same position as in Exp. 167.

Exp. 169. Lay a glass jar on its side (a jar with flat sides is best) and put a sponge, soaked with water, in the closed end. Fit the jar with a cork (bored with a hole for ventilation), and to the inner side of the cork fix a pea or bean seedling by putting two pins through the cotyledons. Fix the cork so that the radicle lies horizontally. Does the radicle bend and grow towards the wet sponge, the plumule towards the mouth of the jar?

Exp. 170. *The Influence of Moisture.* Grow seeds in a box with a bottom of wire gauze, and hang the box up or tilt it by putting a wood block under one end. The radicles grow down through the gauze into the dry air, but they soon curve and grow upwards again. Why?

Exp. 171. Take a tumbler or jar about a quarter filled with water, tie over it some muslin, and on it place some damp sawdust with several soaked seeds, then invert a larger tumbler over the whole. The roots on emerging from the sawdust do not turn back, but grow down in the damp air. Compare with Exp. 170.

Exp. 172. In the middle of a box of dry soil or sawdust place a flower-pot, first plugging the hole in it by a cork. Place some soaked seeds in the sawdust around the flower-pot, but do not water except by pouring water into the flower-pot, and filling the latter up as the water evaporates. After a few days, gently pull up a seedling and see whether its radicle has curved towards the pot.

Exp. 173. In a jar containing some water fix a soaked bean or pea by pins thrust through the cotyledons into the cork (fig. 36). Observe the escape of the radicle and its downward growth. When the radicle is about an inch long, mark it by Indian ink lines, starting at the tip and making a transverse line every 2 mm. ($\frac{1}{12}$ in.) or 3 mm. ($\frac{1}{8}$ in.). Replace the seedling in the jar, and notice that after a day (examine the radicle from time to time) the lines are no longer the same distance apart, but that those near the apex of the root have longer interspaces between them. Further examination will show that growth in length takes place almost entirely in the region just behind the root-cap, and gradually decreases in the regions farther removed from it.

Fig. 36. — Germinating Pea, showing Growth in Length of the Radicle.

Exp. 174 (*another method*). Choose a bean or pea seedling with a radicle about 2 in. long, and mark it as in Exp. 173; then place it in a thistle-funnel, covering the seedling with some moist blotting paper; set the thistle-funnel in a jar or tumbler of water.

Exp. 175 (*another method*). Grow seedlings close to the glass in your glass-sided box, so that the radicles press against the glass (the sloping glass side is best), and mark the glass against the tip of the radicle each day; measure the daily growth in length. How could you find out how the rate of growth is affected by (*a*) light or darkness, (*b*) temperature? If you set several lots of seedlings growing at the same time under different conditions, use a germination jar for each lot.

Exp. 176. Choose a few bean seedlings with straight radicles about 1½ in. long. Dry the radicles gently by stroking with pieces of blotting paper, and mark each radicle at intervals of ⅛ in. by making transverse lines with Indian ink, beginning at the tip. Pin the seedlings to a piece of wood or a cork, and invert it over a wide dish containing a little water. Fix different seedlings with the radicle pointing upwards, downwards, and horizontally. From day to day observe and sketch the appearance of the seedlings.

Exp. 177. Take the jar used in Exp. 173 and cover it outside with black paper or cloth, leaving a narrow vertical chink on one side. Fix a bean seedling horizontally inside the jar, at right angles with the chink. Does the radicle bend, and does it bend towards or away from the light? In which direction does the shoot bend?

Exp. 178. Pass the roots of germinated cress, radish, or linseed through holes in muslin tied over a tumbler filled with water. Set the tumbler close to a window, or in a box with a vertical slit in the side turned to the light, or use a black sheet, as in Exp. 177. Observe the direction in which root and shoot grow with regard to the light.

Exp. 179. To the inner side of the glass in your box with glass front fix with sealing-wax small pieces of wood, some with holes bored in them, and plant seeds a little above these obstacles. Notice that the roots diverge from their course only so much as is absolutely necessary to avoid the obstacles, and resume their original course as soon as they have passed one.

Exp. 180. Another method is to use a glass funnel filled with moist soil or sawdust; plant the seeds close to the glass near the top of the funnel, and fix the obstacles an inch or more below them.

Exp. 181. With the point of a knife remove a small portion of the yolk of a hard-boiled egg, and apply it to one side of the tip of the radicle of a bean-seedling (choose one with a straight radicle about 2 in. long); fix the seedling vertically in a jar containing some water at the bottom (fig. 36), and keep in darkness. After a few hours, see whether any curvature has taken place, and, if so, in what direction? The one-sided irritation, due to the presence of the foreign substance, has exerted a stronger influence than that of gravity, and has caused the bending of the root.

107. **The Root-Tip a Sensitive Organ.** From the foregoing experiments it is clear that the root responds, by changing its direction of growth, to the influences or stimuli of moisture, light, and contact. We have also seen that the main roots always grow vertically downwards, towards the centre of the earth, except when deflected from this direction by one of the stimuli just mentioned. It will be noticed that the shoot of a seedling grows towards light and away from moisture, its responses to these stimuli being the opposite of those made by the main root. The force of gravity also has a stimulating effect on the growth of root and shoot, and the response made is such that the root tends to grow down in the direction of the force, the stem to grow up in the opposite direction. That these opposite tendencies of root and stem are to be ascribed to gravity has been determined by experiment. There is a machine called the **clinostat**, consisting essentially of a plate mounted on a horizontal axis, and therefore rotating vertically. A plant is attached *horizontally* to the plate, and the axis rotated *very slowly.* A little reflection will show that the normal influence of gravity is eliminated, as each side of the axis is, in turn, directed downwards. Stem and root grow in the direction in which they are placed. Another experiment is to attach a plant to a wheel which rotates *rapidly* and *vertically.* Here another force—"centrifugal force"—somewhat similar to gravity, comes into play. If the opposite tendencies of root and stem are to be ascribed to gravity, we should expect similar tendencies to be exhibited under the action of "centrifugal" force. This is the case; in seedlings fixed to the vertically revolving wheel, the roots bend away from the centre of the wheel and grow straight out in the direction of the radius, while the stems grow straight in towards the centre of the wheel. What will happen if the wheel revolves *horizontally*? Two forces now act on the plant, the centrifugal force and that of gravity, and the root bends obliquely outwards, the stem obliquely inwards. Side-roots are but little sensitive to gravity; they grow out from the parent root, each growing in a definite direction. If the growth of a side-root is towards, say, the east, and

it is interrupted by a stone, as soon as the root has reached the edge of the stone it will resume its eastward direction of growth. The branches of the side-roots, again, grow away from these, and may therefore grow in a downward, horizontal, or even upward direction. In the last-mentioned case, therefore, we get some branch-roots actually growing in a direction opposite to that of the main root—that is, making an exactly opposite response to the stimulus of gravity. We have also found by experiments that the attraction-stimulus of gravity may, even in the case of a main root, be overcome by the attraction-stimulus of moisture or by the repulsion-stimulus of light, while contact with an obstacle like a stone causes the root to change its direction of growth for a time, though it resumes this direction as soon as it reaches the edge of the obstacle. It is clear, therefore, that the root is a sensitive organ, its sensitiveness or "irritability" being much the same as that of an animal. It is very important to understand that geotropism and other forms of irritability in plants answer to the various kinds of sensation in animals, and also to try to see the *reason* for each response made by each part of a plant to each kind of stimulus from outside it. If you have carried out the preceding experiments (Exp. 165 to Exp. 181), stop here and think out for yourself *why*—*i.e.* to what advantage—the main root of a bean or pea (or other plant you have worked with) grows downwards, why it grows towards moisture, why it grows away from light, why a root turns off on meeting an obstacle and goes on its former course after getting to the obstacle's edge, why a side-root grows away from its parent-root. In each case, remember the two great functions of the root (what are these?) and the need for the root-system to explore the soil thoroughly and to come into contact with as much soil as possible.

The fact that the removal of the root-tip destroys the power of the root to respond to the stimuli of gravity, etc., goes far to prove that this is the sensitive region of the root, but such experiments are not conclusive, because curvatures due to the injury usually take place; the root sometimes forms a new tip, and then responds to stimuli as

before. The fact that the root-tip alone is sensitive to the stimulus of gravity has been shown by the following method: Seedlings of Broad Bean are caused, by being rotated on a clinostat, to grow into small L-shaped glass tubes, open at one end, so that the root is sharply bent at about $\frac{1}{16}$ in. from its tip. They are then placed in various positions, each having this small glass boot on its radicle. If the tip is vertical, and the basal part of the root horizontal (┌), *no curvature takes place*, though the radicle grows vigorously in the horizontal direction. If the tip is horizontal (L), the vertical part of the root outside of the tube bends until the tip of the root is vertical.

Exp. 182. *Clinostat.* The principle of this apparatus is very simple. Nothing on the earth can be removed from the influence of gravitation, but it is possible to make gravitation neutralise its own effects. A simple form of clinostat, to carry seedlings, is easily made. Here is a method of making one which answers fairly well. Get a cheap but strongly made eight-day clock, and fasten to the axle of the minute-hand a disc of wood about 2 in. in diameter, so that the disc will revolve parallel with the face of the clock. Get a thin, shallow, glass dish (crystallising dish) about 6 in. in diameter, with a cork to fit it, and fasten the cork to the disc with pins. On the cork pin several seeds in different positions, put wet bog-moss between them, and fix on the dish. Get a similar dish and cork, and pin to the latter the same number (three or four) of seeds (Broad or Horse Bean) in the same positions, and fix it upright as a control. The radicles of the seedlings on the fixed cork will all bend downwards, but those on the revolving cork will grow straight out from the seed, and will therefore be directed at various angles.

108. **Regions of the Root.** From your observations on the growth of roots, it will be evident that the increase in length of a root is almost entirely due to the elongation of the region lying a short distance behind the root-tip, also that root-hairs only arise where the root has ceased to lengthen, and that branches only arise still farther back (*why* do not root-hairs and branches arise where the root is still growing in length?). The following regions may be distinguished in a root: (1) Growing-point, covered by root-cap; (2) elongating region; (3) region bearing root-hairs; (4) thickening region, which may bear branches.

109. **The Growing-Point.** A little behind the actual tip of the root lies the growing-point, which is covered and protected by the root-cap. The growing-point consists of cells which are constantly dividing, growing after each division, then dividing again, so as to produce new cells. Most of these cells go to form the main mass of the root, but those formed towards the tip of the root add to the root-cap. The root-cap is, therefore, continually renewed from within as it wears away outside; compare with this the way in which one's skin is renewed. The onward growth of the root is due to the formation of new cells at the growing-point and to their elongation (and further division) behind the growing-point. The growing-point is not only the factory where new cells are made; it is also the sensitive part of the root, which alone can perceive the stimuli of gravitation, etc., and by sending them on to the region behind cause the bending movements we have studied.

Exp. 183. Examine with the microscope the radicles of cress or mustard seedlings, mounted in water on a slide. Focus on the upper surface, and notice the outer layer of cells (skin-layer or epidermis) immediately behind the extreme tip. Sketch part of this, then focus deeper so as to get an "optical section" of the growing-point, and try to make out the tissues as shown in fig. 37, the root-cap covering the denser layers of cells which form the growing-point, and which gradually pass backwards into the central cylinder, the rind (cortex), and the epidermis. Trace the origin of root-hairs, each of which is a long slender tube, closed at the free end; each hair arises as an outgrowth from a single cell of the skin-layer. Farther behind the root-tip the root-hairs are longer, but they are absent from the oldest parts of the root—*i.e.* those nearest the stem. Crush a root by pressing it under the cover-glass, and observe the vessels in the central cylinder; some vessels have a spiral fibre coiled inside them, others show small spots (pits), which are thin places in the

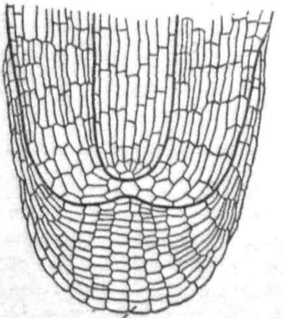

Fig. 37.—The Root-cap, in Section, magnified.

wall. Notice also the large cells of the rind (cortex), mostly elongated in the direction of growth of the root. Try to find the beginnings of side-roots and different stages in their growth (fig. 1).

Exp. 184. Place the root of a bean or pea seedling (try others as well) in some water on a slide, and scrape off the soft outer tissue (epidermis and cortex), first on one side and then on the opposite side. Wash off the scrapings (using your wash-bottle), place on the scraped root some aniline chloride solution, add a drop of glycerine (which makes tissues more transparent), put on a cover-glass, and examine. Notice the yellow-stained wood-vessels, and the long cells associated with them; sketch what you see.

Exp. 185. Cut transverse sections of a bean root at different levels,

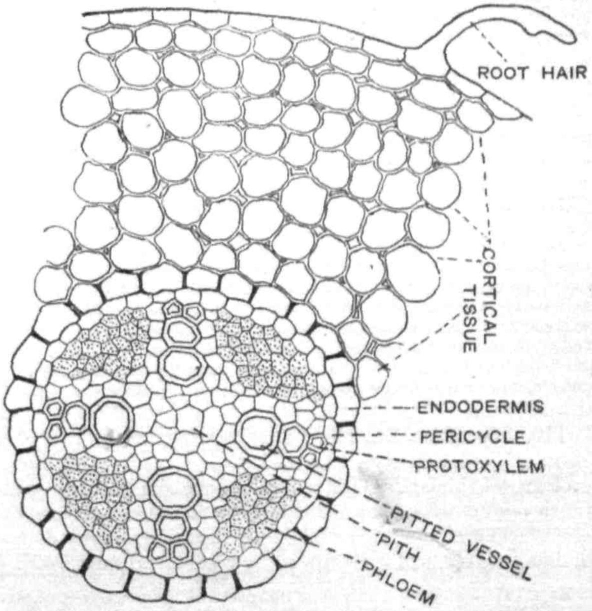

Fig. 88.—Transverse Section of a Young Root of a Dicotyledon with Four Strands of Wood.

starting a little behind the root-tip; it is easier to do this if the root is held between two grooved pieces of elder-pith or of carrot. Keep your razor wetted with 50 per cent. spirit, cut thin sections, stain

some with aniline chloride, others with iodine solution. Notice the tissues shown in fig. 38, the skin-layer, many of whose cells grow out to form root-hairs; the rind (cortex) consisting of cells which are separated at the corners by air-spaces and often containing starch-grains; the central cylinder consisting chiefly of the wood-bundles (stained yellow with aniline chloride), the bast-bundles (*phloem*) alternating with these, the packing-tissue between the bundles, and the sheath surrounding the whole cylinder. The inner wood-vessels are pitted, the outer ones are spiral (Exp. 183), the latter are narrow and are formed before the inner vessels, hence the term "protoxylem" is applied to these outermost and narrowest vessels. The bast-bundles consist chiefly of long tubes, called *sieve-tubes*, because at intervals each is crossed by a partition which is perforated like a sieve, so that the contents (which are proteid substances) can pass through the pores in the *sieve-plates* from one part of the tube to another. The *sheath* consists usually of two layers of cells (*endodermis* and *pericycle* in fig. 38), but these two layers are not very sharply marked in the bean root. The pericycle is a very important layer, because its cells remain capable of dividing and giving rise to new cells; from the pericycle arise (1) the *rootlets*, (2) part of the *new wood and bast* formed as the root grows older and thicker, (3) the *cork* which covers the surface in the older parts of the root.

Exp. 186. In roots of cress, mustard, etc., mounted whole and stained with aniline chloride or red ink, also in sections through roots of bean or pea, notice the formation of rootlets as small swellings (arising from the pericycle) opposite the wood-bundles; these swellings grow out, eating their way through cortex and skin-layer, and escape as small pegs which grow into rootlets. The rootlet is enabled to digest the tissues through which it bores its way, by the cells covering its tip producing ferments similar to those found in germinating seeds. Do you see why rootlets are arranged in a definite number of longitudinal rows?

110. **Secondary Growth.** In older parts of the root of the Bean and other dicotyledons, new tissues are formed, and the root grows thicker. This is because the shells of the sheath (pericycle) outside each wood bundle, together with the cells of the central cylinder which lie inside each bast-bundle, divide actively and give rise to new bast and new wood.

Exp. 187. Cut cross-sections of old parts of the main root of Bean, stain with aniline chloride, and notice the new wood and bast that have been formed; the original wood-bundles (primary wood) can still be seen in the centre of the root.

Exp. 188. In sections of the root of Maize or other monocotyledons, notice the large number of wood and bast bundles; no secondary thickening occurs in these roots.

111. **The Soil** is the medium in which plants may place their roots in such a manner as to enable them to stand erect in the light and air, and it is a storehouse of moisture for the use of plants. The productiveness of a soil depends largely on the amount of water it can hold, and on the readiness and completeness with which plants growing in it can withdraw the water for their use as required. The soil is also the storehouse from which plants get the necessary ash-ingredients of their food, the lime, potash, phosphoric acid, etc., which are formed by the breaking-down and solution of the soil-grains. The soil is also a laboratory in which various lowly plants (fungi and bacteria) are at work breaking down dead organic matter, and converting it into nitric acid and other forms in which it becomes available for the use of higher plants.

112. **The Earth's Crust**. By this term we understand the portion of the earth's exterior which comes within our observation. Its thickness is about 10 miles, so that it represents only a relatively thin layer. Since the average density of the crust (2·8) is just about half that of the earth as a whole, it is clear that the interior must have a very high density, and cannot have either the same chemical composition or physical characters as the outer layer.

113. **Rocks**. A rock may be defined as any mass of naturally occurring solid substance forming part of the earth's crust. Rocks may be divided into two main groups: (1) those formed by cooling, at or near the earth's surface, of masses of molten material, and termed *igneous* rocks; (2) those formed by the accumulation of material derived from pre-existing rocks, and termed *aqueous*, *stratified*, or *sedimentary* rocks. To the former group belong granites and basalts, and most of this group are crystalline rocks To the latter group belong sandstones, clays, limestones; most of these have been laid down under water, and they are not usually crystalline.

114. **Elements of the Earth's Crust.** Comparatively few elements enter into the composition of the common rock-forming minerals (quartz, felspars, micas, hornblende, augite, olivine, calcite, gypsum, kaolin, iron ores, etc.), and about eight out of the eighty elements now known to chemists form about 97 per cent of the earth's crust. The percentages of these elements are: oxygen 50, silicon 25, aluminium 7, iron 5, calcium 3, magnesium 2, sodium 2, potassium 2. Other elements which, though present in relatively small quantities, are widely diffused and of considerable importance, are hydrogen, carbon, nitrogen, phosphorus, sulphur, chlorine. Only six of all the elements mentioned occur in the free state—namely, carbon, oxygen, nitrogen, sulphur, hydrogen, iron, the last two only in very small quantity.

115. **Origin of Soil**. There are many agencies at work in the formation of soils, and the processes of soil-growth are in continuous operation. All soil-material is formed by the breaking down of rocks, and soils may be divided into two classes: (1) sedentary soils, formed from the underlying rock; (2) transported soils, which after their formation have been carried into their present position by water, ice, or wind. A sedentary soil has many of the characters of the rock below it, but is usually darker in colour, owing to the presence of organic matter, or to exposure to the air or to both causes. Between soil and rock there is an intermediate layer, the subsoil, consisting of partly broken-down rock and differing from the soil in texture, composition, and colour. Most rocks consist of fragments or crystals held together by cementing material or by interlocking. The texture is seldom so close as to make the rock impervious to water; even the most close-grained granite or the finest marble will absorb water. The chief agents that cause the "weathering" or breaking-up of rocks and the formation of soil are rain, changes of temperature, frost, the air, earthworms, and the roots of plants. Rain water in falling through the air dissolves oxygen and carbon dioxide, which help it in dissolving minerals in rocks. The oxygen oxidises some of the rock substances—*e.g.* rocks containing iron have a red colour due to iron oxide. The carbon dioxide gives the water an acid action so that it can dissolve carbonates and some other substances insoluble in water alone. The mechanical effect of water in wearing down rocks is well known; soft rocks like clays and sandstones are often broken up merely by the beating of rain on their surface, and even the hardest rocks may be worn down by running water, especially when it carries sand or mud in suspension. Besides the direct action of water, there is the action of water under the influence of frost. If water is in the crevices of a rock when freezing occurs, its expansion pushes asunder masses of rock, and the same action breaks up rock-fragments and further pulverises the soil itself. Apart from freezing, mere change in temperature tends to break up rocks, especially when the change is large and rapid. The sun's heat during the day expands rocks, and the rapid radiation of heat after sunset causes them to cool and contract. The effect of these alternate expansions and contractions is to crack the rock and loosen the particles on the surface, and the effect is increased by the fact that the different minerals in rocks do not expand and contract equally. Even in this country one often notices a difference of about 30° C., and sometimes more, between the temperature during the day and the minimum temperature at night. The air helps in breaking up rocks in two ways: (1) chemically, by its oxygen uniting with other substances and producing softer materials; (2) mechanically, by the wind carrying dust and wearing down rocks, and also causing rain to beat on rock surfaces.

The work of earthworms will be dealt with in Chapter X. For further details regarding soil-formation, books on Physiography or Physical Geography should be consulted.

116. **Sedentary and Transported Soils.** As a rule the rocks from which a soil is derived are found on digging down, but sometimes the soil-materials have been derived from distant rocks by the action of running water, wind, ice-sheets. (1) Sedentary soils, in which the products of weathering remain where they are formed, only occur where the surface is fairly horizontal or where plants are growing. The latter prevent the broken-up material from being quickly carried away by rain, and also by their growth assist in the further breaking-up of the rock. Sedentary soils are chalky, sandy, or clayey, according as the underlying rock was limestone, sandstone, or clay. These form the three chief types of soil, but there are of course gradations from one to the other. In the case of limestone, water containing carbon dioxide often dissolves away the lime and magnesia, leaving the less soluble portions of the rock to form the soil. These portions are usually clay and fine sand, so that a soil formed in this way is often clayey, and may contain less lime than other soils not derived from limestone. (2) The mud carried by every stream after rain is an example of soil in the process of transportation. Another is seen in the way rain washes soil from hill-sides, or from sloping fields (the cultivation of soil helps the action of water in this case, since the surface is repeatedly disturbed by ploughing, etc.). Notice the difference in level of the soil surface where a hedge runs across a slope; the soil carried down the slope is stopped by the hedge or fence, and is gradually piled up against its upper side, while at the lower side the soil is carried away, leaving the hedge or fence higher above the surface. In books on Physical Geography you will find accounts of the formation of deltas, alluvial plains, etc., by rivers, also of the action of glaciers and ice-sheets. In some parts of this country there are deposits of "boulder clay" that have been transported by ice-sheets from other localities.

117. **The Nature of Soil.** The greater part of most soils consists of small fragments of rock of various kinds, usually with varying amounts of organic matter derived from the breaking down of plant and animal tissue. This organic matter, or *humus*, can be removed from the soil by burning it. The soil-grains are coated with substances which have been dissolved in the soil-water, and have been deposited when the water evaporated.

Exp. 189. *Mechanical Separation of Soils.* Get about a pound of garden soil, stir it up in water to form a paste; place this in a jar, fill the jar with water, cork it, shake well for a few minutes, then allow to stand till the soil settles to the bottom. Examine the soil after it has settled; the coarser material at the bottom is *sand*, above this is finer material consisting chiefly of *clay* (the finer grains remain suspended in the water, making it cloudy), and on top of the water floats a little decomposed vegetable matter (*humus*).

Exp. 190 (*another method*). Place a pailful of water on a table,

and dip into it a piece of rubber tubing, to act as a siphon. Get a number of tumblers; into one place a handful of garden soil, and stir it up with water to form a thick paste. Suck water through the tube to start the siphon-action, then direct a weak current (by pinching the tube) into the tumbler containing the soil, having a tumbler below to catch the overflow. The weak current will carry over the finest grains. When the water runs clear, have another tumbler ready, and let a stronger current come through the tube. Notice the time which the grains of different sizes take to settle and leave the water in each tumbler clear.

118. **Sand** consists of grains of various sizes. Sandy soils are called "light" because they are easy to work, though a cubic foot of dry sand weighs about 110 lb., while a cubic foot of dry clay weighs only 70 or 80 lb.; sandy soils are more open, more porous, warmer, and drier than clay soils. A pure sand contains little but insoluble silica in the form of quartz-grains, hence it acts only as a sterile medium, though when watered with dilute nutrient solutions many plants are able to grow well in it. Sandy soils formed from crumbling rocks which have not been much washed by rain-water will, however, contain most of the elements necessary for the food of plants.

119. **Clay.** In clay the grains are smaller than most of those in sand, but they have a tendency to cling together and become cemented into composite grains. In drying, clay tends to form a hard compact mass, impenetrable by the roots of plants; when wet it tends to become sticky and waterlogged. Clay soils are said to be "cold" because they contain more water than sandy soils, but all good soils contain more or less clay, which is richer in plant-food than any other part of the soil. The presence of clay not only increases the power of retaining water, which is very deficient in pure sand, but also increases the percentage of phosphoric acid, potash, and magnesia. Clay is also of great service to plants in "fixing" various substances essential for plant-food, that is, in combining with these substances and preventing them from being too readily washed out of the soil by rain-water. The presence of clay increases the power of retaining water, which is very deficient in sand, but this makes it difficult for a plant growing in a clayey soil to absorb enough water unless the soil contains a large amount. In the latter case, the soil is badly aerated, and hence for lack of oxygen the roots are unable to develop to any great extent or to penetrate deeply. Pure clay consists of kaolin (silicate of alumina), but in ordinary clays the minute particles cemented together consist of quartz, felspar, or even carbonate of lime (in marls), as well as kaolin. The cementing material is a jelly-like (colloidal) form of kaolin, which swells up on being wetted, making the clay sticky and impervious. When pure clay is mixed with water, the muddy liquid produced shows practically no sign of depositing its suspended matter. On adding mineral acids, or salts, or (best of all)

lime-water, the jelly-like clay is clotted (coagulated), and falls to the bottom. Salts of lime are nearly as good as lime-water in causing this coagulation, while alkaline solutions—*e.g.* soda or potash—favour the diffusion of the colloidal clay. Lime is added to clay soils to improve their texture; clay-particles quickly settle when a river flows into the sea.

Exp. 191. Take two similar lamp-glasses, and to one end of each fasten with sealing-wax a piece of perforated zinc, to form a sieve; in each case place a piece of blotting paper in the bottom, covering the zinc. Take two equal quantities of dry clay; place one lot in one vessel as a coarse powder, moisten the other lot, and make it into a paste before pouring it into the other vessel. Fill up each vessel with water, and measure the volume of water which drains through in each case. Another method is to use two funnels, each with a piece of perforated zinc covered with blotting paper or filter paper.

Exp. 192. Powder dry clay, then stir it up in hot water and pour it into two vessels (or test-tubes). To one vessel add lime-water, let both vessels stand, and note the result.

Exp. 193. Using the same apparatus as in Exp. 191 (lamp-glasses or funnels), make a thin paste by working up clay or clayey soil with water, and pour an equal quantity of the paste into each vessel. Fill one vessel up with water (distilled or rain-water if possible), the other with lime-water. Note the time required for 50 c.c. of liquid to percolate through the clay in each case.

Exp. 194. Repeat Exp. 193, using (1) hydrochloric acid, (2) common salt, (3) caustic potash, in solution instead of lime-water.

Exp. 195. Pack clay or garden soil into a glass funnel, then pour in some ammonia-water, and place the funnel over a tumbler. The water will, if the clay is packed tightly enough, come out at the bottom without any smell of ammonia. The ammonia has been absorbed by the silicate of alumina present in the soil.

Exp. 196. Repeat Exp. 195 with (1) dilute solution of caustic potash, (2) dilute solution of phosphoric acid. In each case test the solution with litmus before adding it, and also test the water that comes out at the bottom.

120. **Limestone** (carbonate of lime) may be present as soil-grains or merely as a cementing material to quartz-grains. It supplies plant-food in the form of lime, magnesia, and phosphoric acid. Its action on clay has been mentioned. It also acts as a base with which acids, formed by decay of organic matter in the soil, can unite and thus be made harmless. If such basic material is absent, the soil becomes "sour," through the accumulation of organic acids. Even more important is the part played by carbonate of lime in the process by which certain Bacteria convert into nitric acid the nitrogen existing in organic matter or ammonia compounds; this process only occurs in a weakly alkaline solution, and the nitric acid unites with the lime.

121. **Humus,** the decaying organic matter of the soil, is of great importance both from its physical and chemical properties. It is a light, bulky substance, with high specific heat, great capacity for holding water, and dark colour. The presence of humus gives the soil a loose, open texture, and makes it able to absorb and retain water. In woods, humus often accumulates to a considerable depth, but in ordinary soils it is only present to a depth of about a yard (below which the roots of few plants penetrate), and this part of the soil has a looser texture and darker colour than the underlying subsoil, which contains no humus. Humus contains from 4 to 9 per cent. of nitrogen, far more than is present in the vegetable matter from which the humus is produced. The conversion of vegetable matter into humus is helped by Bacteria and moulds (Ch. X.). If the process of decay occurs below water, the vegetable structure is retained and peat results; if in air, all trace of structure is destroyed by the leaves being passed through the bodies of worms, caterpillars, etc.

Exp. 197. *Microscopic Examination of Soils.* Examine some sand, mounted in water, (*a*) in transmitted light with the mirror, (*b*) in reflected light without the mirror; sketch some of the grains. Examine in the same way some clay, and try to distinguish between the grains of quartz (clear), felspar (cloudy), mica (brown), hornblende (black). Examine some leaf-mould, teased out in water, and make out the remains of leaves, twigs, roots, etc., and the fungus-threads which branch through the decaying vegetable matter.

122. **Classification of Soils.** The different kinds of soils may be grouped under certain generalised headings according to the amounts of chalk, sand, clay, and humus they contain. **Loams** contain 40 to 70 per cent. of clay mixed mainly with sand. If only from 10 to 40 per cent. of clay is present a *sandy loam* results, and below 10 per cent. of clay the soil is merely *sandy*. A loam containing 70 to 85 per cent. of clay is a *clayey loam*, and above this is a *strong clay soil*. The latter when containing up to 20 per cent. of chalk are termed **marl,** and if more than this they are termed *calcareous marls*. Similarly we have *calcareous sand, gravelly loam, chalk loam*, etc., while any soil containing over 20 per cent. of organic matter may be termed a humus soil independently of its other ingredients.

123. **Capillarity of the Soil.** The spaces left between the soil-grains form capillary tubes extending in all directions through the soil. Experiments with soils show that water after sinking downwards can be raised again by capillarity, as the soil dries, from a

depth of more than 10 ft., and thus be available even for roots growing just below the surface. The finer the texture of the soil—*i.e.* the smaller the grains and the narrower the spaces between them—the greater the depth from which water can be raised (see Exp. 39); the capillary rise of water is probably as much as 30 ft. in a fine-grained soil—*e.g.* clay loam. The amount of water evaporated from the surface and of that raised by capillarity is greatly increased by winds; capillary action is stronger in moist than in thoroughly dry soil, just as a cloth or sponge absorbs water more slowly when dry than when wetted. The falling of rain on a dry soil will therefore cause the lower parts to become drier, while the surface layers will gain more water than that represented by the rainfall. The capillary rise of soil moisture is increased by rolling, which brings the upper soil into closer contact with that below; it is also increased by the addition of farmyard manure (why?).

124. **Soil Air.** The capillary spaces in soil are occupied largely by air, if the soil is in good physical condition and not waterlogged (see Art. 58). Great harm is done to plants by over-watering; house-plants are more often killed by this than by anything else. Watering is best done from below; in the case of fields, the best method is to use underground pipes or drains. This supplies both air and water, and if a good *mulch* (*i.e.* a surface covering of manure or raked soil, or anything else that prevents evaporation) is kept up, there is little loss by evaporation. In general, the soil should not contain more than half its total water-holding capacity—*i.e.* about half of the capillary spaces in the soil should be occupied by air (see Art. 126).

Exp. 198. To find out the best percentage of water and of air in the soil for any plant, take five tumblers filled with soil. Add to A 16 c.c. of water each day; to B, 8 c.c.; to C, 4 c.c.; to D, 2 c.c.; to E, 1 c.c. Plant the same number of seeds (small seeds like wheat or cress are best) in each tumbler. After a few weeks notice that those receiving too much water do not grow well because of lack of air in the soil; those receiving too little water will suffer from drought. Select the tumbler which gives the best result, and find out how much *water* the soil contains by weighing a sample of the soil (after stirring it up), then drying it and weighing it again. To find out how much *air* this soil contains, put the tube of a thistle-headed funnel to the bottom of the soil in the tumbler, and from a graduated vessel pour in water till it stands level with the surface of the soil. Since the water displaces the air in the soil, we may consider the volume of water poured into the soil as representing roughly the volume of air it contained; compare this with the volume of the soil.

Exp. 199. To compare the *absorption of water by different soils*, take 100 grm. of gravel, sand, rich loam (good garden or field soil), leaf-mould, and dry, powdered leaves, and put each sample into a wide tube—*e.g.* a lamp-chimney—closed at the lower end by a bored

cork; a glass funnel will do instead. Hold each tube or funnel in turn over a tumbler, and pour into it a litre of water; then measure the water that runs out at the bottom in each case. Which sample absorbs and retains most water and therefore allows least water to run through? In an experiment like this, the weight in grams of the water absorbed by 100 grm. of each dry sample was: gravel, 6; sand, 30; barren sandy soil, 35; rich loam, 70; leaf-mould, 220; leaves, 500. These results show clearly that the water-absorbing capacity of soils is greatly increased by the presence of vegetable matter.

Exp 200. *Evaporation of Water from Soils.* Take 10 tumblers and fill them to within an inch of the top with the following materials: 1, gravel; 2, sand; 3, sandy soil; 4, 5, 6, loam (garden soil); 7, gravel, covered by an inch of sand, with an inch of loam on top; 8, loam covered by an inch of powdered leaf-mould; 9, powdered leaf-mould; 10, water. The materials in tumblers 1 to 9 should be well dried, then an equal amount of water poured into each. Keep the loam in 5 loose at the top by stirring it to a depth of about an inch, and, after adding the water to it, place on the surface an inch of dry, sifted soil. Stir the loam in 6 thoroughly after adding water, and notice that the loam dries in hard lumps after this treatment. Weigh each of the tumblers, and place them together in a position out of direct sunlight. Weigh each day, and record the loss of weight of each due to evaporation of water.

125. **Soil Water.** We have seen that the soil contains spaces between the soil-grains, occupied partly by air. Water occurs in soil under three conditions: (1) *free water*, filling the spaces between the soil-grains and free to move under gravity and to trickle through the soil; (2) *capillary water*, adhering to the surfaces of the soil-grains and to plant-roots in films thick enough to ireow surface tension to move it slowly from place to place, in any dallction where the soil is becoming drier; (3) *hygroscopic water*, which is held around the soil-grains so firmly that it does not move about like the capillary water, and can only be removed by heating to 100° C., when it passes off as steam. Even an "air-dry" soil retains a good deal of hygroscopic water. The free water of the soil is injurious to plants (except those specially adapted—*e.g.* bog- or water-plants), because it interferes with the proper respiration of the root. It is the object of drainage to remove it.

Soil-water contains various dissolved substances—*e.g.* carbonate of lime; phosphate of lime; sodium chloride (common salt); magnesium sulphate (Epsom salt); sulphate of lime (gypsum); silicates of lime, etc.; nitrate of potash (saltpetre); compounds of iron, etc.

It has been calculated that no less than 100 tons of mineral matter is annually removed in solution from every square mile of English country. And half of this amount is limestone.

Now, since there is much diversity in the character and solubility of the rock into which rain-water penetrates, varying as it does from

granite and gneiss to limestone and clay, it follows that the material dissolved must also differ considerably in kind and quantity. Scotland, north of a line joining the mouths of the Clyde and Tay, consists of hard crystalline rock, and the river water of this region contains less dissolved material than any other in the British Isles. Much of the water of North Wales too is almost as free, for similar reasons. England affords a great contrast. Its rounded limestone hills are easily worn away by water, which is rendered acid by the carbon dioxide it has previously dissolved. The gas expelled in bubbles when ordinary water is heated consists partly of carbon dioxide, which was dissolved out of the atmosphere.

Exp. 201. Tie a piece of muslin over one end of a lamp-chimney, fill the chimney with soil, and set it in a basin. Pour water into the basin, and notice its rise in the soil. Are the spaces between the soil-grains filled with air or with water at the beginning of the experiment?

Exp. 202. Spread out some moist soil or fine gravel in a thin layer on a sheet of paper; notice the glistening appearance of the grains. As the soil dries the grains become dull in appearance; why? In moist soil the water is in the form of films around the soil-grains, and the spaces between the grains are filled with air; only in quite wet soil are these spaces filled with water.

126. **Composition of Soil Air.** The air contained in the soil is not enclosed, but is constantly being renewed by diffusion from the air above. Since the processes going on in soil consist largely of oxidation, or are accompanied by oxidation, the soil-air is poorer in oxygen than the air above. In general, the percentages of oxygen and carbon dioxide together equal 21, but that of oxygen varies from 10 to 20 per cent., that of carbon dioxide from 1 to 10 per cent.

127. **Root-Hairs** (see figs. 34, 38) are developed on roots a short distance behind the root-cap. They soon die away from the older parts of the root. They come into very close contact with the earthy particles, so that when the root of a seedling is lifted from the soil, a portion of the latter adheres wherever root-hairs are present, but not where they are absent. They are particularly well seen on seedlings—*e.g.* Wheat, Radish, grown on moist sand in shallow dishes, covered with sheets of glass, to keep the air moist. The surface of the root is increased at least fifty or sixty times by the root-hairs. The root-hairs come into contact with the water around the soil-particles, and each hair becomes surrounded by a film of water. Some roots contain sugar (Carrot, Beet, Parsnip, etc.), and by chemical tests we always find in roots sugar or other substances that are

capable of "attracting" water. We have here the conditions under which osmosis occurs—two solutions separated by a permeable membrane (cell-wall of root-hair), and the soluble substances in the soil-water diffuse into the root-hair, while some of the substances dissolved in the cell-sap of the root-hair diffuse into the soil (see Art. 30, Exp. 38).

Exp. 203. Make a rough model of a root-hair out of a long potato-tuber. Cut off one end of the tuber so that it will stand upright, and with a knife scoop out the middle part, leaving on the outside a layer about a quarter of an inch thick. Half fill the tuber with salt solution or sugar solution (about 5 per cent. in each case), coloured with red ink, and stand it in a dish of water, the level of which should not exceed that of the salt or sugar solution inside the tuber. From day to day observe the rise of the coloured solution, showing that water had been absorbed from outside.

128. **Turgidity**. The process of osmosis through the thin cell-wall of a root-hair is largely influenced by the layer of living substance (protoplasm) within the cell-wall, which allows only weak solutions to pass into the hair, and which retains the water in the cell-sap at a high pressure. The tense condition of the root-hair thus set up is called turgidity. It is really osmotic pressure, regulated by the influence of the living protoplasm layer. If the "artificial root-hair" is placed in a solution stronger than that which is inside it, water is drawn out. Exactly the same occurs with the real root-hair. Its stiffness or turgidity is, like the stiffness of an inflated bicycle-tyre, due to the pressure inside it. This pressure in the root-hair is due to absorption of water—hence, when we draw this water out the root-hair collapses or becomes flaccid. The presence of salts in large amounts in soil-water hinders absorption by the root; this is exactly what the root has to endure in salt-marshes and peat-bogs (Ch. IX.).

Exp. 204. Cut sections of a piece of fresh beetroot; mount sections separately in (1) water; (2) salt solution; (3) alcohol. In (1) notice the layer of protoplasm ("primordial utricle") lining the cell-wall, and the red sap filling the cavity (vacuole) of the cell; some of the cells will be cut open, allowing the sap to escape. In (2) notice that the primordial utricle contracts from the cell-wall, but still contains the red sap, which does not escape from the living cell. In (3) notice that the red sap diffuses out of the cells, which have been *killed* by the alcohol.

Exp. 205. If you have no microscope, the following simple experiment will give you some idea of turgidity. Cut a piece, about 3 by 1 by 1 in., out of a fresh beetroot, and notice the way in which it resists being bent between your thumb and forefinger applied to its ends. Then place it in salt solution, and notice that it bends much more easily (why?); then place it in water until it becomes stiff again (by the cells becoming turgid). Then place the piece of root in boiling water or in alcohol for a few minutes, rinse it in cold water, and see whether it can be made turgid again.

129. **Root Pressure.** We have seen that in root-absorption a very large amount of hygroscopic water with dissolved salts passes into the root-hair, while only a minute quantity of cell-sap diffuses out—a quantity just sufficient to moisten the tips of the root-hairs. This leads to considerable pressure (turgidity) being set up in the root-hair, and when this reaches a certain point the protoplasm of the root-hair undergoes a change, so that it allows the cell-sap to be forced into the cells of the cortex at the base of the root-hair. Each cell in turn, as we pass inwards in the cortex, repeats this process, alternately becoming turgid and collapsing, so that the water with dissolved salts eventually reaches the central cylinder, and is forced into the wood-vessels. Do you see any advantage in the fact that the earliest vessels (protoxylem), which are formed where root-hairs are most abundant and where absorption is active, are at the *outside* of the central cylinder? The effect of the millions of root-hairs absorbing water and passing it on to the cortex-cells, which pump it into the wood, is to produce considerable pressure, which we may regard as a force driving the water into the wood-vessels and upwards; it is called root-pressure. In some plants it is very marked, especially in spring; but it can be demonstrated in most plants while active growth is going on and there is sufficient water in the soil. Many plants "bleed" when cut; this is often seen in trimming or pruning plants, especially in spring or early summer.

Exp. 206. Choose a healthy bean seedling growing in soil in a pot, and cut across its stem about 3 in. above the soil. Tie a bit of stout rubber-tubing, a few inches long, on the stump, and fill this tube with water, then tie into the rubber tube a glass tube of fine bore (capillary tubing). Support the glass tube horizontally by means of a cleft stick; squeeze the rubber tube so as to force some

water out of the end of the glass tube and absorb it with blotting paper, then release the rubber tube so that air is drawn into the glass tube. Watch the advance of the water (which should be coloured with red ink) along the glass tube. Try this experiment with vigorous plants of various kinds growing in pots.

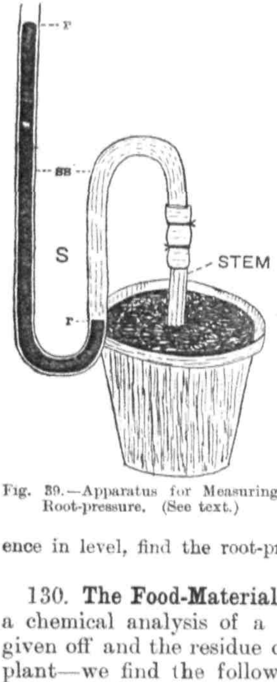

Fig. 39.—Apparatus for Measuring Root-pressure. (See text.)

Exp. 207. Cut off the stem close to the ground, and connect the stump to a long, straight piece of glass tubing; lash this tube to a stick placed in the soil, pour a little water into it, then a drop of oil, which will float on the water and prevent evaporation. Measure the ascent of the water in the tube, and find out how the rate is affected by temperature.

Exp. 208. To measure the force exerted in root-pressure, an apparatus like that shown in fig. 39 may be used. S is a doubly bent (S-shaped) glass tube attached by rubber tubing to the cut stem; it is filled with mercury to the level *s s* Root-pressure forces water into the tube and displaces the mercury to the levels *r r*. From the difference in level, find the root-pressure.

130. **The Food-Materials of a Green Plant.** If we make a chemical analysis of a plant—an analysis of the gases given off and the residue or ash left behind on burning the plant—we find the following chemical elements: carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, magnesium, potassium, iron, sodium, silicon, and chlorine; traces of other elements are sometimes present. Of all these elements, only the first six actually enter into the composition of the living substance (protoplasm) of the plant. It is evident that all the elements found in the plant must enter it in the food-materials absorbed. We shall see later that all the carbon required by an ordinary green plant comes from the carbon dioxide of the air, which is absorbed by the green parts of the plant

(chiefly leaves) in the presence of light (see Ch. IV.). The other elements are absorbed by the roots, usually in the form of nitrates, sulphates, phosphates, chlorides, and silicates of potassium, sodium, calcium, magnesium, iron, and other metals.

131. **Essential Elements of Plant-Food.** All the elements already mentioned, and several others, occur in the composition of plants and their food. In fact, nearly all the chemical elements known to occur in soil, water, and air have been detected in analyses of plants. It has been found by experiment, however, that for most green plants the essential elements—*i.e.* the elements absolutely necessary for healthy growth — are *carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, potassium, magnesium*, and *iron*. It has long been known that a plant can be grown in water containing salts in which all these elements are present with the exception of *carbon*. That carbon is essential is easily proved, as we shall see later (Ch. IV.), yet this element need not be present in the solution supplied to the roots. That all the other elements are essential, and must be supplied to the roots, has been shown by the method of *water-culture*. Several plants of the same species are grown in glass jars (fig. 40), their roots dipping into a culture solution. With most plants there is healthy growth only if the solution contains *potash, lime*, and *magnesia*, combined with *nitric, phosphoric*, and *sulphuric* acids, together with a trace of an *iron* salt.

Fig. 40.—A Plant of Buckwheat grown with its Roots in a Culture-solution.

Exp. 209. Get some large glass jars, each holding at least a quart, for water-culture experiments. Sach's solution consists of 2 grm. of potassium nitrate, 1 grm. each of sodium chloride, calcium sulphate, magnesium sulphate, and calcium phosphate, and a drop

or two of iron chloride (or iron phosphate) to 2 litres of distilled water. Knop's solution, which is perhaps better, consists of 2 grm. of calcium nitrate and 0·5 grm. each of potassium nitrate, magnesium sulphate, and potassium phosphate, with iron as before, in 4 or 5 litres of water. Perhaps the best plan is to get 4 oz. of calcium nitrate and 1 oz. each of potassium nitrate (saltpetre), magnesium sulphate (Epsom salt), and potassium phosphate, and powder these salts to make them dissolve more readily. These quantities will be sufficient for 32 gallons of culture solution; but the latter should be made up as required, so that the above quantity of each salt should be subdivided according to the volume of solution required each time. Grow seedlings of Bean, Pea, Maize, Buckwheat (these answer well, but other plants should be tried, different plants each time you start a series of cultures) until the roots have grown a few inches long, then fix each seedling into a cork or a wooden cover. The cork or cover should have a hole in the centre for the plant, a slit somewhat narrower than the hole running to the edge of the cover (so that the plant can be removed easily when necessary), and another hole for a stick to tie the plant to. Take care to keep the cork, or wooden cover, as well as the part of the plant which is in contact with it, quite dry; most failures in water-culture are due to "damping off" at this part (caused by fungi). If a stick is used to support the plant, there is no need for any packing material; in any case, do not use cotton-wool for this purpose, but soft asbestos which has first been heated and allowed to cool. Darken the roots by covering the jars with black cloth or paper; add water each day to replace that lost by evaporation (using a funnel, and not letting the cork, or wood cover, get wet). Once a month take the plant out, wash its roots gently in a basin of water, pour out the culture solution, and let the plant remain with its roots in plain water for two days before placing it into fresh culture solution. Choose seedlings as nearly equal in size and general growth as possible, then place some in a complete solution, others in a solution from which one or other of the essential elements is wanting. To deprive the plant of potassium, use sodium nitrate instead of potassium nitrate, and calcium phosphate instead of potassium phosphate. Deprive others of calcium by omitting the calcium nitrate; of phosphorus by omitting the potassium phosphate; of magnesium by using calcium sulphate in place of magnesium sulphate; of sulphur by using magnesium chloride instead of the sulphate; of nitrogen by using sodium chloride and calcium sulphate in place of calcium and potassium nitrates; of iron by omitting the iron salt (which should be added in all other cases). The culture solution should not be alkaline, or the roots suffer; if it turns red litmus to a blue colour, add acid (*e.g.* phosphoric acid) until it gives an acid reaction. The roots should be supplied with air; the simplest plan is to force air into the solution every day or two with a bicycle-pump or a condensing syringe.

132. **Essential Soil-Substances.** A soil must contain the same essential elements as the full culture-solution, in order to allow plants grown in it to come to maturity, and these elements must be in a form available for use by the plant. Soil-water contains most of the essential elements in the form of dissolved compounds. The composition of the water present in a soil can be learned by analysis of drainage water, and we can test soils for soluble substances by letting distilled water drain through them and then applying to it tests for the essential elements given above.

Exp. 210. Compare the growth of seedlings (of the same kind of plant) which have been supplied with (1) distilled water; (2) tap water; (3) culture solutions (some complete, others with one element or other omitted in each case). If you grow the plants in washed sand, water with (1), (2), or (3) daily. In either case, compare also with plants grown in good garden soil. After, say, six weeks, dry thoroughly and weigh the seedlings, and compare their dry weights; then burn them and compare the ash weights.

Exp. 211. Dissolve a small crystal of saltpetre in a little water in a test-tube; add a few drops of diphenylamine sulphate, then pour into the tube a little strong sulphuric acid, and notice the deep blue colour produced. This is a useful and delicate test for nitrates.

Exp. 212. Place some dry, fine garden soil in a funnel, plug the tube lightly with cotton wool, and pour water slowly on the soil. Collect the first few drops that ooze through and repeat the test with diphenylamine. A fertile soil always contains nitrates.

Exp. 213. Continue to pour water through the soil in the funnel, and after collecting what comes through, evaporate it to dryness and compare the residue with what is left after evaporating an equal volume of the water used.

133. **Chemical Processes in Soil.** The *inorganic* portion of the soil is subjected to the same actions of air and water as gave rise to its formation from rock (Art. 115). Owing to the large amount of carbon dioxide given off by the decaying organic portion of the soil, minerals like felspar, mica, carbonates of lime and magnesia, phosphate of lime, are exposed to the action of air and of water rich in carbonic acid. The potash, lime, and magnesia contained in these minerals are, by this action, brought into a soluble form and made available for absorption by roots. The soluble salts produced by the action of water, carbon dioxide, oxygen, and other agencies are largely washed out

of the soil by drainage. The chlorides, sulphates, and carbonates are mostly removed in this way; but the soil keeps a firm hold of potassium and ammonium salts and also of phosphates, as can be shown by allowing dilute solutions to filter through soil. The acids of the ammonium or potassium salts are usually found, in the water which runs through, to have combined with lime. The retentive power of the soil for salts of potash and lime and for phosphates is due partly to chemical action between these substances and lime, silicates, acids produced by humus; partly to absorption by the porous and bulky humus; and partly to capillary upward movement in the solution occupying the pores between the soil-grains.

The *organic* portion of the soil undergoes changes which are of surpassing interest and importance, and which have attracted more attention than the changes affecting the inorganic portion. The carbon in the organic matter of soil is continually undergoing oxidation, carbon dioxide and organic acids being produced and heat given off. The air in soil is always poorer in oxygen and richer in carbon dioxide than the air above it. The organic acids produced make the soil "sour" and bad for plants unless there is enough basic material (especially lime) to unite with and thus neutralise these acids. The nitrogen of the organic matter passes eventually into nitrates, available for use by plants. This change, which also occurs in the case of ammonia compounds, is called nitrification.

134. **Nitrification,** like most other changes that occur in organic matter in nature, is due to the action of micro-organisms (Bacteria), which will be dealt with later (Ch. X.). Many Bacteria and moulds have the power of converting the nitrogen of proteids into ammonia, which largely unites with the carbon dioxide produced, forming carbonate of ammonia, and this is oxidised (under the influence of certain Bacteria) into nitrates, ready for immediate absorption by roots. Nitrification can only occur under favourable conditions, the main essentials being: (1) suitable food (certain minerals, especially lime, potash, sulphates, phosphates, also carbon dioxide); (2) basic material

(especially carbonate of lime) to combine with the nitric acid; (3) suitable temperature (lowest about 0° C., highest about 50° C., best about 35° C.); (4) sufficient moisture; (5) sufficient oxygen; (6) absence of strong light, which makes inactive and eventually kills the nitrifying Bacteria. Nitrification is stopped if too much ammonium carbonate is present, as may happen when animal nitrogenous matter is rapidly decaying (*e.g.* when farm-yard manure has been applied); this stoppage is prevented by the presence of gypsum (sulphate of lime) which converts the carbonate of ammonia into sulphate. A chemical change involving the breaking up of nitrates and the setting free of nitrogen takes place under certain conditions in soils and manure heaps. This process, called *denitrification*, is due to the action of certain Bacteria, which can only do their work of destruction in (1) the absence of oxygen, and (2) the presence of large amounts of easily oxidised organic matter in the soil.

135. **Nitrogen-Fixation.** Some Bacteria present in soil have the power of converting the free nitrogen of the air into nitric acid. Some of these "nitrogen-fixing" Bacteria are associated in a remarkable manner with the roots of bean, clover, and other leguminous plants. It has long been known that leguminous crops actually increase the amount of nitrogen in the upper part of the soil, and use had been (and still is) made of this fact by ploughing crops of clover, lupin, etc, into the soil ("green manure"). The root-nodules of leguminous plants contain a micro-organism which fixes free atmospheric nitrogen, and thus enables these plants to flourish in the absence of a supply of combined nitrogen in the soil. The life and work of micro-organisms will be more fully described later (Ch X.).

136. **Available Plant-Food in Soil.** We have seen that root-hairs can only absorb dissolved substances. Salts insoluble in pure water and required by plants are brought into solution in various ways, chiefly by the carbon dioxide present in soil-water and by the changes due to the various chemical processes we have just mentioned. It is easy to

prove that root-hairs give out acid sap, and that they give out carbon dioxide, which accounts partly, at any rate, for the acid reaction they give with litmus. In these different ways the elements essential for plant-food are made available for the use of plants. A complete chemical analysis of a soil, though giving the limits of the plant-food the soil can supply, often gives little practical information as to its fertility or its need for manures. It is necessary to know, as far as possible, the amounts of the essential elements which are directly available for the use of plants. One method, used to determine the amount of available phosphoric acid and potash, is to treat the soil with a 1 per cent. solution of citric acid, which represents the average acidity of the sap of roots and root-hairs.

Exp. 214. Grow seedlings with their roots resting on wetted blue litmus paper, or dipping into blue litmus solution, and notice the change of colour, due to the acid substances excreted by the root-hairs.

Exp. 215. Grow seedlings in a layer of sawdust or soil resting on a slab of polished limestone. After a week or so, when the roots have reached the slab, remove the latter and examine the surface closely for the tracks eaten into it by the roots.

Exp. 216. To show that roots give out carbon dioxide, it is only necessary to grow seedlings for a short time with their roots dipping into lime-water; set up a control experiment, with a jar containing lime-water but no plant.

137. **Fertility of Soil.** From what has been already said, it is easy to understand that the fertility of a soil depends on the existence of suitable relations between its (1) mechanical, (2) chemical, and (3) biological properties. (1) No matter how rich a soil may be in plant-food, it cannot reach a high degree of fertility unless it has the proper fineness of texture, porosity, water-holding power, and other physical properties which are essential to allow the roots of plants to grow readily in it and be supplied with sufficient air and water. (2) It is also essential that the soil contains a suitable store of plant-food in an available condition. However suitable the structure of the soil, it cannot give the best results if the plant-food (or any essential part of it) is present in insufficient amount or in an insoluble or unavailable form. (3) Since the conversion of one of the

most important elements in plant-food, nitrogen, from combination in complex and insoluble organic substances into the directly available nitrates, is the work of certain micro-organisms, it is obvious that these organisms must be present in the soil in order to make it highly fertile.

138. **How Soil is Improved.** There are various methods of improving the soil and making it fertile or keeping it so. The physical condition of soil is improved by tillage operations (*e.g.* ploughing, harrowing, rolling, draining), also by adding to the soil materials which alter its mechanical properties (*e.g.* lime or bulky vegetable refuse). Improvements in the chemical condition of soil are made by (1) adding substances which contain plant-food, (2) adding substances which act upon insoluble compounds present in the soil and make available the plant-food they contain. The chief methods of improving soil, then, are *tillage* and *manuring*.

139. **Tilth.** The physical condition of a soil is called its *tilth*. A soil consists of grains of various sizes, and it is in good tilth when the grains are neither too fine nor too coarse, and when they are not too firmly cemented together. Since the soil-grains are more or less rounded, when they are massed together without being crushed a large amount of space exists between them; this space is required for movements of air and of water. If the grains are too large and too loosely packed, the soil lets rain fall through it too freely, and does not bring it back rapidly enough, by capillarity, to meet the needs of plants. If the grains are too small and too closely packed, the water moves too slowly, too much is retained by capillarity, and there is too little air. If the grains are bound together too strongly, the soil is too hard, and roots cannot grow freely in it. A soil is in good tilth when the soil-grains are of the proper size and there is a good circulation of air.

140. **Tillage.** This term is applied to the different methods of working or tilling soil in order to secure the conditions necessary for the growth of cultivated plants. The chief objects of tillage are (1) to destroy weeds; (2) to place below the surface manure and other organic matter, where it may be rapidly converted into humus; (3) to modify the condition of the soil in regard to openness of texture, temperature, movements of soil-water and of soil-air. The early tillage of the soil before sowing in spring has for its main objects the changing of the soil-texture so as to make the soil warmer, drier, and better aerated, also to diminish the rate of evaporation of the deeper soil-water, and to hasten the germination of weed-seeds so that the weeds may be destroyed before it becomes difficult to get them out owing to the presence of the crop itself.

141. **Tillage Tools.** Different tools are used for tilling the ground when different objects are aimed at, also according to differences in texture of the soils dealt with. The *plough* is used for two chief purposes: (1) to alter the texture, forming from a comparatively hard soil a deep layer of earth; (2) to bury below the surface manures or weeds, where they will decay and be converted into plant-food. The plough tends to divide the soil into thin slices, which glide over one another as the furrow-slice is thrown up. To cut a clean furrow-slice and turn it over so as to completely cover the surface, a long and gently sloping blade is used (sod-plough). To thoroughly crush and grind the soil by bending the furrow-slice as abruptly as possible before it is turned over, a shorter and steeper blade is used (stubble-plough). Soil which is very open, porous, and cross-grained should usually be ploughed with a steep blade and strongly curved "mould-board," so as to make the texture closer. When soil is heavy and close in texture, it needs the less steep blade and more gently curved mould-board (sod-plough) so as to shear it into thicker slices and form larger grains. Again, the less steep type of blade is used when the soil is too wet, the steeper blade when it is too dry. You can easily find out more on this subject of tillage by watching the work done by farmers at different times of the year. The *roller* is used chiefly to firm the surface, to cover seeds, to crush clods or the furrow-slices formed by ploughing. The rolling of the surface layers of soil tends to draw the deeper soil-water to the surface, and the wind blowing over the smooth rolled surface with increased velocity causes evaporation. To remedy this, the *harrow* is used; the harrow is also used to give a fine surface tilth as a preparation for the seed and to uproot weeds.

142. **Manures and Fertilisers.** Various materials are applied to the soil in order to replace certain elements which in time become deficient owing to the growth of plants and to loss by drainage. The chief elements which it is necessary to replace in this way, in order to keep the soil fertile, are *nitrogen*, *phosphorus*, and *potash*. *Lime* is also used largely, but more on account of its action on other soil-substances than as direct plant-food. Manures are usually valued according to their richness in nitrogen, phosphorus, and potash. "Chemical" manures or fertilisers are used to supply one or other of these elements, while the more complex "natural" manures contain varying quantities of all the chief essential elements.

143. **Natural Manures.** *Farmyard manure*, containing the remains of the vegetable substances used as food and litter, is rich in nitrogenous compounds, which are mostly insoluble, but are gradually broken up, by the action of Bacteria, into soluble nitrogenous substances and also into ammonia and nitrogen gases. Manure heaps smell strongly of ammonia gas (which contains over 80 per cent.

nitrogen), but this gas and the nitrogen escape into the air and are lost unless the manure is mixed with soil, which absorbs the ammonia. *Humus*, consisting of peat, leaf-mould, and other decomposing plant remains, is applied to the soil by ploughing in straw, peat-moss, weeds, etc.; it decomposes slowly, forming ammonia and also acids, which help in the production of soluble plant-food. *Guano* (dung of sea-birds) is not so much used now since the original Peruvian guano-deposits (which contained nearly half its weight of ammonia-compounds, together with phosphates and potash compounds) became exhausted; the guanos now obtainable contain less nitrogen, but often more phosphates. *Bones* are used in many forms in manuring soils; they consist largely of phosphate of lime, together with organic matter. The latter includes fat, which hinders the breaking up of the organic matter when crushed bones or bone-meal is applied to soil; the fat also forms a lime soap as an impervious crust on each fragment of bone Bones are often treated with steam under pressure to extract the fat and the gelatine, or with acid to dissolve the calcium phosphate (leaving behind the organic matter from which glue is made), which is precipitated by lime.

144. **Chemical Manures.** Substances of mineral or artificial origin are largely used to supply certain elements of plant-food, chiefly nitrogen, phosphorus, and potash. The use of such "fertilisers" enables the farmer to supply what he considers necessary, without introducing other plant-food with which his land may already be well provided. Their extensive use in farming has led to a far more scientific treatment of the soil than was possible with complex natural manures only. When the soil is deficient in one essential element, a small quantity of fertiliser containing this element in a suitable form will give valuable results with little outlay. Before using fertilisers, it is obviously desirable to know in what essential elements the soil is lacking, and although chemical tests (soil analyses) are useful, the simplest and most practical method is to apply different fertilisers to small portions of the soil which is to be dealt with, and comparing the crops raised in each portion or "experimental bed."

145. **Nitrogenous Fertilisers.** The chief mineral substances used to supply nitrogen are nitrate of potash (Chili saltpetre), sulphate of ammonia (made from the "ammoniacal liquor" of gas-works), and, to a much smaller extent, nitrate of potash (saltpetre). Of Chili saltpetre, the world's annual consumption has reached about one and a half million tons, about one-tenth of which comes to Great Britain. The supply is fast becoming exhausted, but recently large quantities of nitric acid have been manufactured by causing atmospheric nitrogen and oxygen to combine with water, by means of an electric furnace, the nitric acid being then combined with lime to form calcium nitrate. The process of making nitric acid from the nitrogen of the air is also carried on by the action of certain

Bacteria in the soil (Art. 134 ; Ch. X.). Sulphate of ammonia is used even more largely in this country than nitrate of soda; but whereas the latter can be at once absorbed by plants, sulphate of ammonia must undergo nitrification in the soil before its nitrogen is available for plant-food. For this process to occur, carbonate of lime must be present to form calcium nitrate with the nitric acid produced, and to form calcium sulphate with the sulphuric acid set free. Nitrate of potash, though a valuable fertiliser, since it supplies both nitrogen and potash in a directly available form, is not much used, on account of its high price as compared with nitrate of soda.

146. **Natural Sources of Nitrogenous Plant-Food.** The chief *natural* sources from which green plants obtain nitrogen are: (1) the nitric acid and ammonia-salts brought down in rain; (2) nitrates produced by micro-organisms in the soil, the nitrogen and oxygen being obtained from the air; (3) nitrates produced by the micro-organisms which inhabit the root-nodules of leguminous plants; (4) the products of the nitrification of organic substances present in the soil, effected by micro-organisms.

There is little doubt that almost all the combined nitrogen occurring in nature has been formed from the nitrogen of the air by the action of micro-organisms in the soil.

147. **Phosphatic Manures.** Several of the natural manures are used chiefly for the phosphates they contain—*e.g.* guanos, steamed and burnt bones. Of greater importance are various fertilisers containing phosphates of lime, the chief being "superphosphate" (a mixture of lime sulphate and phosphates) and "basic slag" (a by-product in the Thomas-Gilchrist process of making steel from pig-iron rich in phosphorus). Phosphatic manures of all kinds need to be finely divided to make them readily available to plants.

148. **Potash Manures.** Potash is much more widely distributed and less often deficient in soils than any of the other essential elements. Certain crops, especially grass, potatoes, and leguminous crops, are greatly benefited by potash manures. Formerly the chief source of potash was the ash left when plants are burnt; the "wood-ashes" contain phosphates, lime, etc., but are especially rich in potash. The great saline deposits in Germany (Stassfurt, etc.), which now yield nearly all the potash used in the world, consist largely of chloride and sulphate of potash, mixed with other substances. The most widely used potash manure is kainite, which contains about 20 per cent. sulphate of potash, together with common salt and salts of magnesia.

149. **The Uses of Lime.** The chief effect of "liming" the soil—*i.e.* applying lime or its carbonate—is to hasten nitrification and thus help the crop to use the nitrogenous substances present in the soil. Lime also acts by neutralising

the organic acids in peaty soils; by replacing the potash in silicates; and by its "flocculating" or coagulating effect on clay, which is in this way made friable and easily worked. Gypsum, or "land plaster" (sulphate of lime), often gives good results, especially with clover and turnips; it helps in nitrification, and it sets potash free from the silicates in the soil.

Exp. 217. If a garden or field is available for experiments with fertilisers, arrange a set of beds, each bed a yard square, separated from each other by at least a yard (to prevent the fertiliser from diffusing), and in each bed place a different fertiliser, working it into the soil with a spade. Find out from farmers or seedsmen the amount of each fertiliser used per acre and divide to find the quantity required for a square yard (an acre = 4840 sq. yds.). In each bed sow wheat or other crops (change them each year), and keep the watering and other conditions as nearly alike as possible in all the beds. Leave one bed without fertiliser; on the others place one of the following: (1) farmyard manure (well rotted), about 1 lb.; (2) Chili saltpetre, 1 oz.; (3) superphosphate, 1 oz.; (4) kainite, or carbonate of potash, 1 oz.; (5) quicklime, 1 lb.

Exp. 218. Another method is to place the soil, well mixed with one or other of these fertilisers, in pots, using quantities corresponding to the area of the soil-surface. Use a series of pots for each fertiliser, placing different quantities in each pot, and grow the same kind of plant—*e.g.* wheat—in each set of experiments. The other conditions—*e.g.* watering, exposure to light—should be kept as nearly uniform as possible in all cases.

150. **Selective Absorption by Roots.** It is well known to farmers that on most soils it is better to change the kind of crop grown from year to year, instead of growing the same crop year after year. This is because different plants have different needs, and take their food elements in different proportions from the soil. For instance, cereals (Wheat, Rye, Barley, Oats) take from the soil less than half as much nitrogen, lime, and potash as "root-crops" (Turnip, Mangold, Beet, Potato). Hence crops with similar needs are raised alternately, instead of in succession, on the same field; this alternation is called the "rotation of crops." When a plant is grown in a solution containing sodium nitrate (Chili saltpetre), it takes up all the nitrogen and only a trace of the sodium, because more nitrogen is used by the plant than sodium.

151. **Roots as Storehouses of Food.** In annual plants the food produced by the plant during the growing season is mostly turned at once into new tissues. The only store of reserve food is that laid by in the seed for the use of the young plant when germination occurs. In biennial plants (which in the first year produce leaves and make and store up food, and in the second produce flowers and fruits) reserve food is often stored in the roots, which are greatly thickened, as in Carrot, Beet, etc. In these cases the so-called tap-root really includes part of the stem in addition to root proper, and in Turnip and Radish the whole of the swollen part corresponds to the hypocotyl of the seedling. In perennial

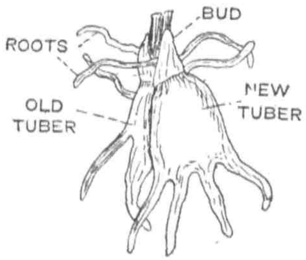

Fig. 41.—Palmate Tuber of an Orchid.

plants the roots may be annual, as in Lilies and other plants with bulbs or rhizomes (see Ch. V.); or biennial, as in Dahlias; or perennial, as in shrubs and trees. Roots that are annual—*i.e.* perishing the same year in which they are formed—contain no reserve food; but roots that last two or more years nearly always contain more or less food for the following year's growth. Adventitious roots may be used for the storage of food, as in the tuberous roots found in many *Orchids* (fig. 41). The tubers may be either palmate or globular, and they arise adventitiously from buds which appear at the base of the present year's stem. Next year a new stem develops from this bud at the expense of the nutriment stored up in the tuber. In the case of the Dahlia and Paeony, adventitious tuberous roots grow out

from the base of the stem (fig. 42), and these are put to a similar use as storage houses for reserve-materials. That these bodies are really roots is shown by their development as irregular endogenous outgrowths at the base of the stem, which do not arise in the axils of leaves and are at first covered by a root cap.

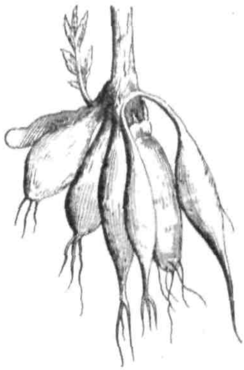

Fig. 42.—Tuberous Roots of the Dahlia.

Exp. 219. In Radish seedlings, make sketches of young plants of different ages, showing the cotyledons and the red hypocotyl, the thickening of the hypocotyl, and the fully formed swelling. Cut thin cross-sections of the root (hypocotyl) of a young seedling, and notice the very marked circular transparent zone of growing tissue (*cambium*); test with iodine and notice the starch present in most of the cells except those of the cambium. The cambium consists of narrow oblong cells, arranged in radial rows, filled with protoplasm, and are continually dividing to form new cells on the outer side (bast) and on the inner side (wood) of the cambium-layer; the wood contains but few vessels.

Exp. 220. Study and compare the roots of Carrot, Parsnip, Beet. The Beet root is peculiar in having several layers of cambium instead of one only. Scrape the root of Carrot and that of Parsnip, put the scrapings in warm water, shake up, and filter. Test the filtrate for sugar with Fehling's solution. The reserve food in the Beet is also sugar, but it is cane-sugar, not glucose, as in Carrot, etc. Hence in order to get the red precipitate with Fehling's solution, it is necessary to boil first with sulphuric acid in order to convert the cane-sugar to glucose

Exp. 221. Dig up entire plants of the Early Purple Orchis and of the Lesser Celandine, wash off the soil, and examine the tuberous roots. Test cut surfaces of these tubers with iodine. In Orchids the root-tubers are developed from buds produced at the base of the season's shoot. In the following year the buds develop into new aerial shoots at the expense of the material stored up in the tubers.

Exp. 222. Examine the tuberous roots of Dahlia, which are formed in summer and store up food to be used by the flowering stems of the next year (fig. 42). When exhausted of food they die off, but new tubers are formed as the old ones are emptied, so that the individual plants can carry on a perennial existence. The reserve

food in this case is inulin, similar in composition to starch, but differing in being soluble in water; so that in a section of fresh root examined in water the cells appear empty. If a piece, or a section, of Dahlia tuber be placed in alcohol for some time, the inulin is deposited in the cells as rounded crystal-like masses (fig. 43).

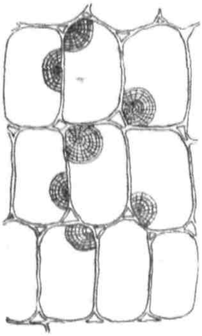

Fig. 43.—Cells with Inulin-Crystals.

152. **Other Functions of Roots.** We have in this chapter considered the main functions of ordinary roots (namely, to fix the plant in the soil, to absorb water with dissolved salts, and to conduct this water upwards to the shoot) and one of their secondary functions (food storage). Roots have other functions than these in certain cases, the most important being found in plants whose nutrition is partly or wholly *saprophytic* (*i.e.* at the expense of decaying vegetable matter) or *parasitic* (*i.e.* at the expense of other living plants). These will be dealt with in Ch. VIII.

QUESTIONS ON CHAPTER III.

1. Describe simple experiments to show by what paths water travels through the plant from roots to leaves.

2. What common plants have contractile (and therefore wrinkled) roots? What is the use to the plant of the contraction of the roots?

3. What are the main functions of roots? How are they adapted to carry on these functions?

4. What is meant by calling plants "surface-feeders" or "deep-feeders"?

5. How is the radicle of a seedling enabled to penetrate stiff soil? How may the force exerted by the radicle in entering the soil be measured?

6. How can it be proved that the direction of growth of a root is a response to the stimulus of gravity? Explain the term "geotropism."

7. How is the direction of growth of a root affected by moisture? Why is it advantageous to the plant that the stimulus due to moisture is able to overcome that due to gravity?

8. How is the direction of a root's growth affected by light? How does a shoot differ from a root in this respect?

9. How is the growth of a root-tip affected by contact with a hard obstacle?

10. How can it be proved that the root-tip alone is sensitive to the stimuli of gravity, light, etc.?

11. In what part of a root does growth in length occur? How can it be proved that the curvatures in response to stimuli (gravity, light, moisture, contact) also occur in this part?

12. Describe the characters of the various regions of a root, starting from the extreme tip.

13. What are root-hairs? Where do they occur, and what is their function?

14. Why should a farmer keep his crops free from weeds? In what way are weeds harmful, if this is not done?

15. Describe the chief agencies by which soil is formed. What are the differences between "sedentary" soils and "transported" soils?

16. What are the chief constituents of ordinary soil, and how may they be separated?

17. Describe the characters of sand, clay, limestone (chalk), and humus, with reference to the growth of plants.

18. Draw up a general classification of soils.

19. How do the chief soil-constituents differ as to capillarity, ability to retain water, and usefulness as sources of plant-food?

20. What substances are found dissolved in soil-water? Describe the three conditions in which soil-water exists? Why is excess of free soil-water injurious?

21. How does soil-air usually differ from that in the atmosphere?

22. How do root-hairs help the root to absorb the water of the soil as thoroughly as possible? Under what conditions will root-hairs be (*a*) abundantly, (*b*) scantily developed?

23. What is root-pressure? How is it set up, and how can it be demonstrated and roughly measured?

24. What are the essential elements of an ordinary green plant's food? In what forms are these elements obtained?

25. What is meant by "water-culture"? Name the substances which are used in making up a culture-solution for a green plant?

26. How could you prove that nitrates (of soda, potash, or lime) are present in a fertile soil?

27. What chemical processes occur in (*a*) the inorganic, (*b*) the organic, portions of the soil?

28. What is meant by "nitrification"? What is its importance in plant-life, and under what conditions does it occur?

29. What is meant by "available plant-food" in the soil? Explain why some soils may be rich in the essential elements of plant-food and yet be poor soils in which to grow plants.

30. How are plants enabled to make use of substances in the soil which are not soluble in water? What part do root-hairs play in the process?

31. What is meant by a "fertile" soil? Upon what conditions does the fertility of a soil depend?

32. In what ways can a soil be improved, both as regards its texture and its richness in plant-food?

33. What is "tilth"? What tools are used in tillage, and what is the mode of action of each?

34. Why is it necessary to use manures and fertilisers on cultivated soils? Mention the chief fertilisers used, and the reason for using each of them.

35. What is meant by "liming," and what useful effects has this process on the soil?

36. What is meant by "selective root-absorption," and how is it related to "rotation of crops"?

37. What special function is performed by the roots of most biennial plants and some perennials with regard to food-storage?

38. What is a soil? What is meant by "light" and "heavy" soils? What are their respective advantages and disadvantages for the growth of plants? Give any instances you know of rocks or strata which produce light and heavy soils respectively.

39. Explain how you would investigate the rate of growth in length of a root, indicating the precautions you would observe in conducting your experiments. Illustrate your answer by a diagram.

40. Show how some of the commoner operations of gardening, such as digging, manuring, raking, transplanting, and watering, may be conducted, so as best to minister to the chemical and physical conditions of plant-life.

41. Explain how you would proceed to make a water culture. Indicate the effect, on the plant, of the omission of salts containing calcium, potassium, and nitrogen, respectively.

CHAPTER IV.

THE GREEN LEAF AND ITS WORK.

BEFORE starting detailed work on leaves, refer to the parts of Ch. I. which deal with the leaf of the Broad Bean. Then gather and examine leaves of various kinds, living or fallen, evergreen or deciduous, stalked or unstalked, simple or divided (compound). What is there common to nearly all leaves, however they may differ in detail? In what surroundings do you find plants with thick fleshy leaves? Does the general broad and thin form of the leaf-blade suggest anything as to the functions of the leaf? Do most leaves seem to expose as much surface as possible to light and air? We saw that the seed-leaves of Broad Bean and of many other plants contain food, and that if they are removed from a soaked seed which is beginning to germinate, the growth of the young plant is stopped.

Exp. 223. Remove the *foliage-leaves* from (1) a young bean-plant which has not yet used up the food in its cotyledons, (2) an older plant whose cotyledons have fallen off (if they have shrunk considerably, but are still attached, pull them off). Does the removal of the foliage-leaves check the growth of the plant, as compared with that of similar plants left untouched? In which case, (1) or (2), is the effect greatest?

153. **Comparison of Cotyledons and Foliage-Leaves.** We have seen that the cotyledons of the Broad Bean resemble the later leaves in the fact that branches arise in their axils. By growing a seedling in coloured water it can be shown that the cotyledons have veins, which can also be seen in sections examined with the microscope. It is always a useful plan to tabulate—*i.e.* to write down in parallel columns—the chief differences between different plants or different parts of the same plant, as regards their

position, form, structure, etc., and then to find out as completely as possible, by observation and experiment, the *reasons* for these differences. In comparisons of this kind, always try to discover whether differences in *structure* can be explained as due to differences in *function*.

Seed-leaves (cotyledons).	Foliage-leaves.
opposite	alternate
small	large
simple	compound
pale yellow	green
thick	thin
veins obscure	veins conspicuous
no stipules	stipules present
remain below ground	formed above ground
gradually turn smaller	gradually turn larger
fall off after a time.	remain on a long time.

Can you add any further differences? Try, as you proceed with your study of the green leaf and its work, to explain these differences in form, texture, duration, etc., between the cotyledons and the foliage-leaves of the Broad Bean.

It is important to know something of the structure of a leaf before proceeding to the study of its functions.

Exp. 224. The following is a good method of examining the structure of a leaf. Boil some small entire leaves (those of Box or Privet answer well) in caustic potash for about ten minutes. Hold a leaf under water, and with scissors cut off a strip round the margin; the leaf is then readily separated, with the aid of a mounted needle, into three parts, which should be mounted on separate slides and examined with the lens, and then covered with a cover-glass and examined with the microscope. The three parts are (1) the upper skin or epidermis, (2) the middle tissue or mesophyll, containing the veins, (3) the lower skin. The upper and lower skins are thin and transparent, each one cell in thickness; they are, of course, continuous with each other at the edge of the leaf. In the upper skin all the cells fit closely together without any spaces between them, but in the lower skin there are numerous openings (stomates). Tease the middle tissue with needles, so as to separate the cells in one portion; notice the shapes of these cells, some being cylindrical, others branched. You will probably find some of the cylindrical cells still attached to the inside of the upper skin, and some of the branched cells inside of the lower skin. Notice the spiral and pitted vessels in the veins.

Exp. 225. Dip the leaves of various plants into very hot (just boiled) water in a warmed tumbler, and notice the expulsion of air-bubbles. In many leaves the bubbles only appear on the lower surface, *e.g.* Laurel, Rhododendron; in others they appear on both sides, but more abundantly on the lower surface, *e.g.* Broad Bean. Cut a large leaf (*e.g.* Laurel) across and dip the cut edge under water, observing the streams of bubbles given off.

Exp. 226. Try to blow through leaves dipping into water, first with the stalk and then the blade under water. Suitable leaves are Lesser Celandine, Arum, Chinese Primrose, Marsh Marigold.

Exp. 227. Even when one cannot force air through a leaf with the lungs, the presence of air-spaces and of openings on the surface can easily be shown by using an air-pump or exhausting syringe to suck air through, or a bicycle-pump to blow air through. The leaf-stalk should be fixed in a bored cork, with another hole for a short glass tube to connect with the syringe or pump by means of rubber-tubing. The cork is fixed into a wide-necked flask or bottle, and the whole made air-tight by means of plasticine and vaseline.

154. **Minute Structure of the Leaf** (fig. 44). Every leaf is covered externally by a layer of flattened cells, known as the epidermis, and the outer walls of the epidermal cells

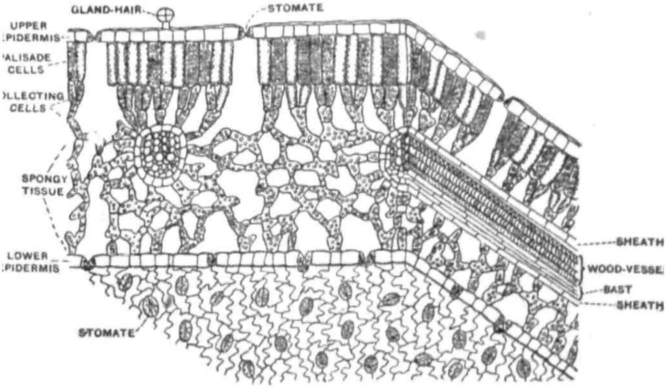

Fig. 44.—Structure of Part of a Broad Bean Leaflet.

form a distinct cuticle, which is especially well developed in plants grown in dry situations. The cuticle is impermeable to water, and acts as a protection against drying.

Hence it is easy to understand why the cuticle should remain undeveloped in plants which grow submerged in water. The epidermis is discontinuous at certain points, leaving narrow oval apertures called **stomates**, each of which is surrounded by a pair of special curved guard-cells. The latter are able to open or to close the stomates, for when they are quite tense (*turgid*) they curve apart, but when less so, they collapse and come together. The stomates are very minute but extremely numerous, and in *bifacial* leaves which have distinct upper and under surfaces, they are either more abundant on the under surface,* or are entirely restricted to it. The centre of the leaf is occupied by ground tissue, through which strands of conducting tissue run, the latter being the "veins" of the leaf. In bifacial leaves the ground tissue (*mesophyll*, or central leaf-tissue) is usually divided into an upper region in which its cells are long and narrow in the vertical direction (*i.e.* lengthened at right angles to the surface of the leaf), and a lower region in which the cells are branched and loosely arranged. The upper tissue (palisade tissue) is compact, the cells being close together or separated only by narrow spaces, whilst the lower tissue (spongy tissue) contains large spaces between the cells. The cells of the palisade and spongy tissue all contain green grains; so do the guard-cells of the stomates, but not the other cells of the epidermis, nor those making up the veins. It is easy to discover that the spaces between the cells of the middle tissue of the leaf contain air, and that they communicate with each other throughout the leaf, with the air-spaces in the corresponding tissue (ground tissue, cortex) of stem and root, and with the external air by means of the stomata. It is also easy to show that the green grains present in the middle tissue (mesophyll) and in the guard-cells contain a green substance (*chlorophyll*, or leaf-green) which can be dissolved out of the grains, leaving them colourless; the grains are called *chloroplasts*.

* A square millimetre of Broad Bean leaflet gave, as the average of several countings, 90 stomata in the upper epidermis and 140 in the lower; a leaflet with area 10 sq. cm. therefore bears over 200,000 stomates.

Exp. 228. Fold a large leaf (*e.g.* Laurel or Rhododendron) several times, and cut thin sections, keeping the razor wet with alcohol. Mount in water, examine with a microscope, and sketch a thin part. Cut some sections with the razor dry, and mount in water; notice the presence of numerous irregular air-bubbles between the cells of the spongy tissue, then run in some alcohol and observe the expulsion of most of the air in the form of spherical bubbles. This shows that the spaces between the cells of the spongy tissue contain air. How did this air get in? Examine thin sections and try to find stomates leading into the air-spaces.

Exp. 229. Strip off a piece of the lower epidermis (Broad Bean, Narcissus, Arum, and Ivy-leaved Toadflax answer well), mount in water, and examine with the microscope. Notice the stomates (are they open or closed?) and the presence of chlorophyll-grains in the guard-cells (do they occur in the other cells of the epidermis?). Find an open stomate with the high power, put a drop of 3 per cent. salt solution at one side of the cover-glass, and draw it through with blotting paper. Notice the effect of this on the stomate. Now put a drop of water at one side and draw it through, until the stomate opens again. Sketch the stomate opened and closed. The salt solution draws water out of the guard-cells, and then the stomate closes as the guard-cells lose their turgidity and collapse. When water is added, the guard-cells absorb it and swell up, becoming turgid, and the stomate opens.

155. **Do Leaves contain Food?** We have seen that seed-leaves often contain food-materials—*e.g.* starch, proteids, oils. It will be easy to find out whether foliage-leaves contain any of these foods. Let us test them for the presence of starch, by using iodine solution. To do this we must try to remove the green colour.

Exp. 230. Boil in water some leaves taken from a bean seedling, or some other plant with thin flat leaves, which has been growing in the light. The colour does not come out. Place the boiled leaves in alcohol, and notice that the leaves gradually lose their colour, while the alcohol turns green. Try several different plants; in some the extraction of the chlorophyll takes place very slowly, in others (*e.g.* Broad Bean, Tropaeolum or "Nasturtium," Primrose) much more quickly. When the leaf is colourless, place it in a saucer and pour dilute iodine solution over it. The depth of colour produced shows roughly how much starch is present. If there is abundance of starch, the colour is nearly black; if little starch, it is bluish; if none, the iodine turns the leaf brownish (test for proteids).

Exp. 231. Place in darkness for two days the plant used in Exp. 230, and then try the iodine test on its leaves, first boiling them in water and then placing them in alcohol to extract the chlorophyll. (Do not *boil* leaves in alcohol, which is rather

dangerous; if you want quick extraction of chlorophyll, use the plants you find most suitable, after trying several, in regard to being decolorised in cold alcohol). No starch is present.

Exp. 232. Keep a plant in darkness until the leaves no longer show starch when tested with iodine, then cut off several leaves and set them in tumblers or bottles of water; the stalk should dip under the water. Set some in sunlight, the others in darkness, and after two days decolorise and test with iodine the two lots of leaves. Those kept in darkness show no starch, but starch is found in those that have been exposed to light. This means that starch is *made* by leaves when in the light, but not when in darkness.

156. **Light required for Starch-Formation.** The preceding experiments show that starch is found in leaves that have been exposed to light, whilst it is absent from the leaves of the same plant after it has been kept in darkness for a day or two. This suggests (1) that light is required for starch to appear in the leaf, (2) that the starch formed in the light disappears in darkness.

Exp. 233. Set some plants—*e.g.* Broad Bean, Primrose, Tropaeolum —in pots in darkness for at least a whole day. In the morning take off some of the leaves, decolorise them, test with iodine; they give only a light brown colour, starch being absent. Choose a day with sunshine or good diffused light for these experiments:

(*a*) Let some of the leaves on the plant remain untouched.

(*b*) Fix a strip of tinfoil across the leaf, on both sides (above and below); or pin to the leaf two flat slices of cork opposite each other on the two sides; or stitch to the upper side of the leaf a piece of black paper or cloth. The object in each case is, of course, to exclude light from a portion of the leaf.

(*c*) Smear the lower *surface* of another leaf with vaseline; this will block the stomates, which in many leaves are mostly or even entirely found on the lower surface. Find out the distribution of stomata on the two sides of each leaf you experiment with by tearing off and examining with the microscope pieces of the lower and the upper epidermis. If you have no microscope, dipping the leaf into hot water gives a rough idea on this point (Exp. 225).

(*d*) Smear a small circular area of the leaf with vaseline, applying it to both sides, so that this part of the leaf will be shut off on both sides from communication with the atmosphere through the stomata.

(*e*) Smear with vaseline the *upper* surface of another leaf.

(*f*) Smear *both* surfaces of another leaf.

In each case expose the plant to light from morning till late afternoon, then take off the leaves which have been treated in these various ways, tying to each a label, decolorise them and test with iodine solution. Make notes of your observations and con-

clusions as to the conditions under which starch is made by leaves. After being tested with iodine, the leaves may be preserved in alcohol and thus made colourless again, and on being soaked in hot water will again give the starch reaction with iodine. *The same leaves can therefore be used again and again;* starch once formed remains in the leaf when it has been killed by boiling.

Exp. 234. Vary Exp. 233 (*b*) by cutting the words "starch," "light," your initials, etc., in capital letters out of a card; fasten each card to a broad leaf (a primrose plant, dug up and grown in a pot, or in a jar of water, answers well), and, after letting the plant stand for a full day in darkness, expose it to light for several hours, then decolorise and test.

Exp. 235. Try variegated leaves (*e.g.* varieties of Geranium or Ivy), making a careful drawing of each leaf before it is decolorised and tested with iodine, and observe that only the green parts produce starch. In leaves whose veins are colourless, or nearly so (*e.g.* Primrose), owing to the absence of chlorophyll above and below them, you will notice that the veins stand out from the rest of the leaf when the iodine-test is applied, by the absence of starch.

Exp. 236. In Exp. 54 we prevented the access of air to seeds by covering them with water, and in Exp. 233 (*c*), (*d*), (*e*), (*f*), we have excluded air by covering the leaf with vaseline. Tie the stalks of the leaves of some ordinary land-plants to a stone and sink them under water in a glass jar. Expose to light, and afterwards test the leaves for starch.

Exp. 237. Repeat the last experiment with the leaves of a plant which lives submerged in water—*e.g.* Water Starwort, Canadian Water-weed—or any other plant you find growing below water in ponds or streams. Do these submerged leaves possess stomates in their epidermis?

Exp. 238. Has temperature any influence on the starch-production of leaves? Place a leaf in a saucer or jar kept cold by ice, expose to light, and after several hours test for starch.

Exp. 239. Cut sections of leaves that have been exposed to light for several hours. Examine some sections to see what parts contain green grains (chloroplasts); then treat others with alcohol and test with iodine. Notice that starch-grains occur only in cells which contain chlorophyll. Tear off bits of the upper and lower epidermis-layers, and notice that only the guard-cells of the stomates contain starch.

Exp. 240. Grow seedlings (Bean, Pea, etc.) in darkness, then put them in the light for a day and test the leaves for starch. Leave them in the light until their leaves turn green, then test again for starch. The results show that the green substance (chlorophyll) is essential for the process of starch-making by leaves.

Exp. 241. What becomes of the starch formed in the foliage-leaves? Is it absorbed by the plant, like the starch in the seed-

leaves of the bean? If so, we ought to find less starch in the leaves in the morning than in the evening, since the leaf cannot make more starch until it is again exposed to light. Remove some leaves from a plant in the early evening (an hour or two before sunset) and place them in alcohol. Early next morning remove some more leaves from the plant, and also cut out differently shaped pieces from some of the leaves and place them in alcohol overnight; then compare their starch-test with that given by the rest of the leaf the next morning.

Exp. 242. In Exp. 241 the starch formed in the leaf during the day was found to have disappeared, more or less completely, in *darkness, while the leaves were still attached to the plant. Would* the starch have disappeared had the leaves not been left on the plant? Repeat the experiment, but cut some of the leaves off, set them in a tumbler with their stalks under water; cut pieces out, test them for starch, then test the rest of each leaf in the morning.

157. **How Starch disappears in Darkness.** We saw that the starch stored in the bean cotyledons is on germination converted by the action of a ferment (diastase) into sugar, which is soluble in water and therefore able to travel by diffusion to the growing parts of the young plant and supply them with food. We have seen that the leaf when exposed to light produces starch, which disappears during the night, and if we cut out small pieces from the same leaf every day and tested them, we should find that the alternate production and disappearance of starch go on day after day. By cutting out pieces of leaf of a certain area, drying them and weighing, we should find that the dry weight of the leaf is increased at the end of a sunny day, that it decreases after some hours of exposure to darkness, increasing again on exposure to light. These facts suggest that the starch formed in light is digested and carried away during darkness, and we find that the leaf-cells produce *diastase* just as do the cotyledon-cells in the bean seedling.

Exp. 243. Keep a plant in darkness for two days, then expose it to sunlight for several hours. Remove some leaves, dry them in a slow oven *(or on a sand-bath), then* powder them and let them soak in cold water for about half an hour. Filter the extract thus obtained, and try its effect on starch-paste, testing with iodine, and later with Fehling's solution. An extract of leaves of "Garden Nasturtium" or of Broad Bean, made in this way, quickly converts starch into sugar; try these and other plants.

158. **How is Starch made by Leaves?** We have seen by experiments that starch is made by a foliage-leaf (1) when it is exposed to light, (2) when its stomates are open (no starch is formed when they are blocked with vaseline); also that it is only made by green leaves, and only by the green parts of a leaf. It is clear, therefore, that *light*, *air*, and *chlorophyll* are all concerned in the production of starch by the leaf. We may now try to find out *how* these are concerned in the process, and what part each plays in it. We already know a good deal about *air* and about *starch*, but we have not yet studied *chlorophyll* and *light*.

159. **How is Air concerned in Starch-making?** We know from previous experiments that starch can be broken up, by heating it, into carbon dioxide and water; that carbon dioxide is always present in the air, being produced by all processes of burning when the substance undergoing oxidation contains carbon; that a plant increases in dry weight when grown in a culture solution which contains no carbon, though more than half of the plant's dry weight consists of carbon. If you consider these facts carefully you will probably conclude that the carbon in the starch made by the leaf comes from the carbon dioxide in the air. Does the leaf in some way make carbon dioxide and water come together to form starch? If so, a plant which is exposed to light and is making starch must be taking carbon dioxide from the air. Again, if the carbon dioxide of the air is the source of the carbon used in starch-making, what will be the effect of exposing green leaves, in light, to air containing no carbon dioxide?

Exp. 244. Heat in a dry test-tube (1) pieces of laundry-starch, (2) leaves, (3) pieces of stems, (4) pieces of roots, (5) any other plant tissues. Notice that water is given off as vapour which condenses in the upper part of the tube, and that a black charred mass remains (charcoal, *i.e.* carbon). Fix a J-shaped tube into a cork to fit the test-tube, and let the longer limb dip into lime-water in a bottle or test-tube; notice that carbon dioxide is given off, causing a white precipitate, when these substances are strongly heated. These experiments show that all parts of plants contain carbon, and that starch (the formation of which in plants has been proved in the preceding experiments) also contains carbon.

Exp. 252. Keep your water-plants in darkness until the leaves show little or no starch, then transfer them to water which has been boiled (to expel the dissolved gases) and then cooled. Expose them to light, with funnel and test-tube as before. Is any oxygen given off by the plants, and do they make any starch?

160. **How is Water concerned in Starch-making?** When starch is heated, carbon dioxide and water are given off. This suggests that possibly carbon dioxide and water are in some way brought together, in the cells of a green leaf in sunlight, to form starch. This is not exactly what happens, but the fact that a water-plant can, when supplied with water and carbon dioxide, make starch (containing carbon, hydrogen, and oxygen) suggests that water must be concerned in the process. Some acquaintance with the chemical properties of water is necessary before we can explain the facts which we have learnt from the preceding experiments.

161. **Composition of Water.** Water is a *chemical compound*. This can be proved by passing an electric current through water, by means of a piece of apparatus known as a Voltameter (fig. 45). The current is produced by an electric battery (not shown in the figure), and brought to the water by one wire, and carried away by the other. The wires end in metal plates projecting up into the water. Over each of these plates is placed a test-tube, filled with water and with the open end downwards under the surface of the water in the vessel. As soon as the current begins to pass, bubbles are seen to appear over the surface of the two metal plates. These bubbles soon float up into the test-tubes, and the gases they contain accumulate at the top of each tube. It will soon be seen that the formation of bubbles is much more rapid at one plate than at the other, and as the gases collect we find there is

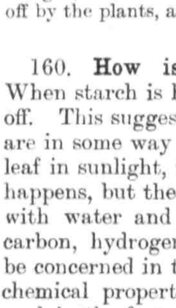

Fig. 45.—Analysis of Water by the Voltameter.

exactly twice as much of one as the other. When enough has collected, we can stop the current, remove the test-tube with the greater amount of gas, covering its open end with the thumb before lifting it out of the water, and then turning that end upwards. On removing the thumb and applying a light, this gas is found to burn with a blue flame. This gas is called *Hydrogen.* Examining the gas in the other tube in the same way, we find it does not burn, but it allows other substances to burn in it in a more active way than they do in the air. This gas is in fact *Oxygen,* the constituent of the atmosphere which takes part in the process of combustion. We have thus *analysed* or split up water into two substances.

That water is really composed of Oxygen and Hydrogen in chemical combination can be shown by the reverse process—*synthesis*—that is the production of water from Oxygen and Hydrogen. This is done by passing an electric spark through a mixture of the two gases in the proper proportions, when water is formed.

162. **Water contrasted with Air.** Both air and water have been shown to consist of two gases: air, of nitrogen and oxygen; water, of hydrogen and oxygen. It is true the constituents of air cannot be distinguished by the microscope, and diffusion prevents their separation into a heavier and lighter layer. Small quantities can, however, be partly separated by simple solution in water (for oxygen dissolves more readily than nitrogen), and also by other physical means. But air is formed directly nitrogen and oxygen are *mixed* together; and there is no evidence of chemical reaction, such as rise of temperature, explosion or burning, or alteration in volume, which usually accompany *reaction* between gases. Further, the known gaseous compounds of nitrogen and oxygen are nothing like air in their chemical properties: for one (nitrous oxide) is the anæsthetic so frequently used by dentists, and the other (nitric oxide) on exposure to air forms poisonous brown fumes. They are totally different also from either of the constituents of air.

The properties of air, on the other hand, are intermediate between those of oxygen and nitrogen. To a certain extent it resembles both. Thus it supports combustion like oxygen; but not so actively as the pure gas, a modification we might expect from the large proportion of inert nitrogen mixed with it.

A mixture of hydrogen and oxygen, however, is not water. It becomes water only on the elevation of its temperature to the

ignition point of hydrogen, when the usual accompaniments of chemical action referred to above become manifest. The properties of the steam produced, too, are altogether different from those of either hydrogen or oxygen. It does not burn, neither does it support the combustion of ordinary inflammable bodies; and when cooled it condenses to a liquid state, which makes the difference more striking still. Both the elements are present in the steam, yet no longer separate and independent, but united by some mysterious force which we call chemical attraction.

163. **Photosynthesis.** We may now begin to use another term for what we have so far called "starch-making." We shall see later that what occurs in the green leaf exposed to light and air is a somewhat complicated series of processes, leading usually (but with some exceptions) to the appearance of ***starch*** at one stage. What we have learnt from our experiments on plants, together with our knowledge of the composition of water and of carbon dioxide, would seem to suggest that a process of *synthesis* occurs in the green parts of plants. We have seen that one method of proving the composition of water is to produce it by synthesis—*i.e.* by bringing together hydrogen and oxygen gases and making them unite to form water. Many complex substances, *e.g.* sugars, can be produced by synthesis. These facts suggest that in the green plant carbon dioxide may be broken up into its elements (carbon and oxygen), and its carbon made to unite with water, or else that both the carbon dioxide and the water are broken up and their elements (carbon, hydrogen, and oxygen) re-arranged in such a way as to produce carbohydrates.

164. **Energy required for Photosynthesis.** We have seen that water cannot be broken up into its elements, hydrogen and oxygen, except by spending a large amount of energy (in the form of electrical energy, see Art. 161). To break up carbon dioxide also requires the spending of much energy. If this gas is passed over heated charcoal, the latter absorbs some of the oxygen present in the dioxide, and we get a gas with different properties (carbon monoxide) which contains only half as much oxygen. To break up carbon dioxide into carbon monoxide and oxygen gases requires a temperature of over 1000° C. In our laboratories,

therefore, we can effect the decomposition of carbon dioxide and of water only by the expenditure of a large amount of energy—heat energy in the former case and electrical in the latter. The building up of complex substances also means expenditure of energy. The green plant carries on both these processes at ordinary temperatures. Light being an essential factor, we come to the conclusion that it is so because it is the chief source of energy. The energy used is stored up in potential form in the organic substances produced, *e.g.* starch. We have seen that starch is not formed in the absence of *light*, even when all the other necessary conditions are present (what are these conditions?). This fact is of course expressed in the term photosynthesis, which is more suitable than "carbon-assimilation," a term also applied to the process we are now studying.

We must therefore study some of the chief facts concerning Light.

165. **Cause of Light.** Light, like heat, is believed to have its origin in vibration of the molecules of the luminous body, and to be transmitted to the eye by means of undulations in an intervening medium. And, since light can pass freely through a perfect vacuum and through interstellar space, the medium required for its transmission cannot be of a molecular nature. It is an imagined continuous substance which is called the *ether*. It is quite unlike any form of matter with which we are acquainted. It is probably devoid of weight, and is perfectly elastic. The ether is supposed not only to occupy all space, but to interpenetrate all matter, and to lie between the molecules of even the densest solids, as air lies between the leaves and branches of a tree.

It may now be possible for us to picture to ourselves the vibration of the molecules of the luminous body setting up wave-movements or undulations in the ether which travel with inconceivable speed * in all directions. Some of these undulations, falling on the eye, there set up changes in the optic nerve, which, when transmitted to the brain, produce the sensation of light.

166. **Light is Invisible.** Remembering what light is—simply undulations in an invisible medium—this statement ought to cause little surprise. When we apparently see a beam of sunlight entering through a small window into an otherwise dark room, what we really see is not the light itself but a number of floating dust particles in the air illuminated by the beam. Many of these are so large as to

* About 186,000 miles per second, a speed that would carry it $7\frac{1}{2}$ times round the earth in a second.

be easily visible separately as dancing motes. If a lighted Bunsen burner be brought below the beam so as to burn up or volatilise these particles, the luminous track will be interrupted by what appears to be black smoke rising from the flame. But the Bunsen flame is perfectly smokeless, and the black spaces are full of dust-free air; consequently there is nothing in those parts to reflect the light, and it remains invisible.

167. **Light travels in Straight Lines through the Same Homogeneous Medium.*** If two screens be pierced with small holes and then held one in front of the other, in such a position that the two holes and a candle are in the same straight line, a ray of light can pass from the candle through the holes to an eye placed in the same straight line behind the screens; but, if either of the screens be but slightly displaced in its own plane, the candle becomes invisible. In this experiment the same medium (air) extends between the eye and the object seen; but when light passes from one medium to another it is in general bent out of its direct path.

168. **Intensity of Light.** Light, like radiant heat, is a form of energy, and therefore capable of measurement. The quantity of light in any space at any instant is measured by the corresponding amount of energy in that space at the instant considered, and the intensity of the light is measured by the energy transmitted through that space in unit time. This measurement cannot be made directly; but, for light of a given colour, the intensity is proportional to the brightness as perceived by the eye, and also to its heating effect.

169. **The Law of Inverse Squares.** In fig. 46 we see a lamp radiat-

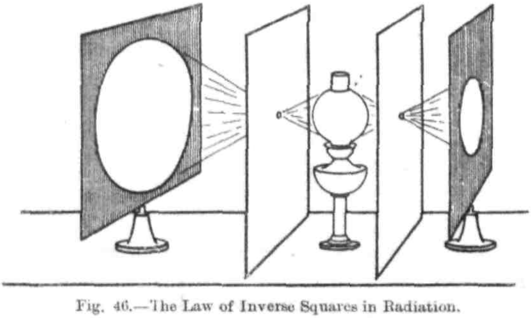

Fig. 46.—The Law of Inverse Squares in Radiation.

ing its light on to two surfaces, one of them at twice the distance of the other. The same amount of light falls on both, but it is spread

* A medium is any substance through which light passes, and it is homogeneous when it is uniform in composition, structure, and physical state.

out over a circular area of twice the diameter (and therefore four times the area) in the more distant one compared with the nearer one. Hence a unit of area (a square centimetre) of the distant surface only receives one-quarter the light that falls on a unit area of the nearer surface. In general terms, the amount of light received on any area varies *inversely as the square of the distance* from the source of light.

170. **Photometers.** Photometry is the experimental comparison of the illuminating powers of different sources of light, and the different forms of apparatus by which this comparison is effected are called *photometers.* The practical unit employed in photometry is the light emitted by a standard sperm candle (six to the pound), burning 120 grains per hour; and hence the illuminating power of any source of light is generally expressed as being equivalent to that of a certain number of standard candles. It has been found that the eye is unable to estimate the ratio of the intensity of illumination due to different sources of light, but that it is a correct judge of the equality of the illumination of two adjacent surfaces. For this reason all methods of photometry depend on the equalisation of two illuminations.

If a sheet of paper, having a spot of grease on it, be held up to the light, it will be seen that the spot of grease is semi-transparent, and looks brighter than the rest of the paper when viewed from the side remote from the light, but darker when seen from the other side. The reason of this is evident; more light passes through the region of the grease spot than through the rest of the paper, and hence when seen from the side remote from the light it looks brighter than the rest of the screen through which little or no light passes; when looked at on the other side, however, the spot looks comparatively dark, because a large proportion of the light incident upon it passes through, and is therefore not spent in illuminating its surface. It will now be understood that if the screen be placed between two sources of light, and its position adjusted until the spot cannot be seen on either side, except by close inspection, then the screen must be equally illuminated on both sides.

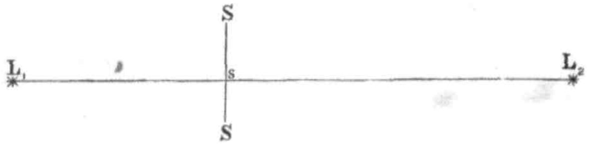

Fig. 47.

If L_1, L_2, and S S (fig. 47), represent the relative positions of the lights and the screen when finally adjusted, we have—

$$\frac{L_1}{L_2} = \frac{(L_1\, s)^2}{(L_2\, s)^2}.$$

In carrying out measurements, at least four different adjustments should be made: (1) Adjust for disappearance of the spot when seen from the side of screen facing L_1. (2) Turn the screen round through 180°, and again adjust for disappearance of spot from the same surface now facing L_2. (3) Repeat (1) and (2) with the other surface of the screen.

The screen is usually mounted in a light frame, so that it can be easily turned round in its stand, or as a whole.

It will be noticed that the method described above assumes the truth of the law of inverse squares, and the consistency of the results obtained is the best proof of the truth of this law. A direct verification of the law may, however, be effected by comparing the illuminating power of a single candle with that of four similar candles arranged together as one source of light. It will be found, on adjusting for equality of illumination, that the distance of the four-candle source from the screen is twice that of the single candle.

171. **Effect of Light-Intensity on Photosynthesis.** It is easy to show that the rate at which a green leaf makes starch varies according to the intensity of the light. In weak light no starch is formed, and this is also the case when the light is too intense, but between the two extremes the amount of starch formed corresponds roughly with the light-intensity.

Exp. 253. Cover half of a leaf with thin paper, or a piece of ground glass, and expose it to sunlight; test for starch and note result.

Exp. 254. Place some healthy cut branches of Elodea (see Exp. 250) or other water-plant under water, and select one which gives a good stream of oxygen-bubbles (fairly rapid and constant) from its cut end. Count the time required for, say, 10 bubbles to be given off, and repeat the counting several times till you get a fairly constant result. Then remove the jar into the shade, or cover it with a sheet of thin white paper to weaken the light, and take times as before, noting the change in the rate of bubbling.

Exp. 255. Repeat Exp. 254, but cover the jar containing the water-plant with a black cloth except at one side, and throw light on the plant by placing an incandescent gas-lamp, acetylene lamp, or electric lamp at different distances from it, noting the distances and the rates of bubbling. Bring the lamp into such a position that bubbles begin to come off, and count the rate; when it becomes fairly constant, bring the lamp to half this distance from the plant and count again. A good deal of the effect, however, is due to the heat given out by the lamp; a flat-sided bottle, or other vessel, containing water (kept cold by constant renewal) should be used as a screen to absorb the heat.

172. **Refraction.** We have seen that a ray of light travels in a straight line so long as its course lies in the same homogeneous medium, but when it passes from one medium into another, in any other direction than perpendicularly to the common surface, it undergoes a change of direction at the surface of separation of the two media. This change of direction is called **refraction**. In illustration of this phenomenon the following simple experiments are frequently adduced :

Exp. 256. Partly immerse a straight stick in water in an oblique position. It will appear bent at the surface of the water. This is due to the refraction of the rays coming from points of the stick below the surface of the water.

Exp. 257. Place a coin at the bottom of a vessel with opaque sides, in such a position as to be just hidden by one of the sides ; it will be found on pouring water into the vessel that the coin soon becomes visible.

For similar reasons a pool of water appears shallower than it really is, and small air bubbles in solid glass objects appear nearer the surface than they actually are.

173. **Dispersion.** White is not a pure colour, but a mixture of colours ; that is to say, white light consists of a mixture of various coloured lights in a certain proportion. When white light passes through prisms and lenses not only is it refracted, but its coloured components are more or less *dispersed*—*i.e.* separated from each other.

174. **Prisms.** By a prism is meant any solid figure whose ends are similar and equal polygons and whose sides are parallelograms. The prism most commonly used is a three-sided piece of glass, but prisms of four or more sides are used, and, instead of glass, rock crystal, Iceland spar, rock-salt, or any other transparent solid may be used. Or, instead of using glass by itself, we may have a hollow glass prism to contain water, turpentine, bisulphide of carbon, or other liquids.

The *refracting edge* of a prism is the edge formed by those two faces through which the light under consideration is passing.

Let ABC (fig. 48) represent a cross section of a prism and BAC the refracting edge considered; then, if the material of the prism be of higher refractive power than the external medium, a ray RN incident on the face AC at N is bent towards the normal on entering the prism, and, taking the course NN′, is incident on the face AB at N′, where it is bent away from the normal, and leaves the prism by the path N′R′.

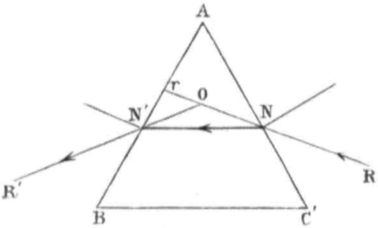

Fig. 48.

Exp. 258. The light coming from the sun was first shown by Newton to be of a composite character. In its simplest form Newton's experiment may be performed in the following way. A beam of sunlight is admitted into a dark room through a small circular aperture, A, in a shutter or blind. This beam will be seen

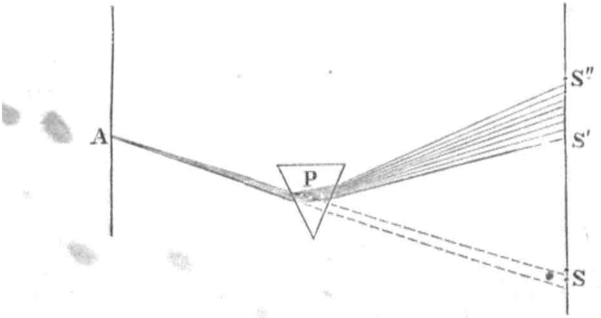

Fig. 49.

in the room as a small pencil of light diverging from A (fig. 49), and, if allowed to fall on a vertical screen at S, it forms a small elliptical bright spot, which is a rough image of the sun. If sunlight be not available, a parallel beam from a small hole in a cap covering the condensing lens of an optical lantern may be used. Now place a

prism, P, with its edge downwards and horizontal in the path of the beam, which will be deviated from its original course, and deflected upwards so as to form an image at S′S″. This image differs from that first formed at S in several important particulars; the vertical diameter is much longer, and instead of appearing as a bright patch on the screen, it is made up of coloured bands arranged horizontally. In fact, the image is made up of an immense number of overlapping images, similar in shape to that originally seen at S, but each of a different colour. This shows that the beam of *white light* incident on the prism is, on refraction through the prism, separated into different coloured constituents, each of which forms its own image on the screen, and thus the many-coloured compound image at S′S″ is formed. Such compound images are called *spectra*.

175. **Spectrum.** When a *spectrum* is formed by decomposition of the solar light, as in the case we have just considered, it is called the *solar spectrum*. In it we can easily recognise *six* principal colours, *red*, *orange*, *yellow*, *green*, *blue*, and *violet*. Of these, the red rays appear at S′, the bottom of the image S′S″, and are, therefore, the least deviated. The violet rays are found at S″, the top of the same image, and are therefore the most deviated. The intermediate rays are arranged in the order given above, from below upwards, between S′ and S″.

Attentive observation will at once show that the number of coloured components of white light is not six only, but infinite, since they merge into each other by imperceptible gradations.

When the rays of a compound beam of light are refracted through a prism, as in Newton's experiment, each constituent suffers refraction to a different extent. This is sometimes expressed by saying that the constituents of the compound beam are of different *refrangibilities*; the most *refrangible* rays are those which undergo the greatest deviation, while the least *refrangible* are those which suffer least deviation. In the *solar spectrum* the red rays are the least refrangible, while the violet rays are the most refrangible. The intermediate rays increase in refrangibility as we pass from red through orange, yellow, green, blue, and indigo to violet.

Beginning at the less refrangible end of the spectrum, and travelling in the direction of increasing refrangibility, we pass a group of rays known as the *dark heat rays*, which do not excite the sensation of sight. Then we come to

another group, *the visible spectrum*, ranging through the colours red, orange, yellow, green, blue, and violet. This group of rays, in addition to possessing heating properties, has the peculiar property of exciting the optic nerve, and thus producing the sensation of sight. In this visible spectrum the intensity of the light is different in different parts, being a maximum in the yellow and gradually diminishing on both sides towards the red and violet. Beyond the visible spectrum are the *dark chemical rays.* These extend for a considerable distance beyond the violet, and are characterised by their power of producing chemical action in certain substances.

The complete spectrum is thus made up of the *dark heat rays*, *the visible spectrum*, and the *dark chemical rays*. The only essential difference between these is that of wave-length, which *continuously* increases from the first to the last. All these rays have heating and chemical properties in different degrees and under different conditions, but only those of the visible spectrum have the power of exciting the sensation of vision.

176. **Which Light-Rays are concerned in Photosynthesis?** It is fairly easy to test this by comparing the effects of exposing plants to light of different colours—*i.e.* allowing only certain rays to fall upon the leaves. It is found that photosynthesis is effected almost exclusively by the less refrangible rays, especially the *red*, while the rays at the blue and violet end have little to do with the process.

Exp. 259. A rough comparison may be made by setting a plant, or a leaf with its stalk dipping into a bottle of water, in a box, one of whose sides is replaced by a sheet of *red* glass, another in a box with a side of *green* glass, another with *blue* glass. After several hours' exposure to light, test each for starch. However, coloured glass is hardly ever pure, in the sense of allowing only rays of one colour to pass through it. This can easily be seen by testing coloured glass with a spectroscope (an excellent direct-vision spectroscope can be had for 25*s*.) or with a lantern and prism.

Exp. 260. A better method is to use a pair of double-walled bell-jars, the space between the two walls being filled with a coloured solution. One should be filled with watery solution of potassium dichromate; the other with watery solution of copper sulphate, to which ammonia has been added. The first solution allows red rays to pass through, the second one blue rays. Set each bell-jar on a

folded cloth, or in a saucer of dry sawdust, so as to shut out any white light, place under each a plant in a pot or a seedling that has been dug out and had its root set in a bottle of water. Set both bell-jars in diffused light; in direct sunlight the temperatures in the two would not be the same (why ?). The plant in the red-orange light will be found after exposure to light (let the experiment last for two days) to have formed abundant starch, that in the blue light will be almost free from starch.

Exp. 261. Watch the bubbles of oxygen arising from a submerged water-plant (see Exp. 254), and time the rate of bubbling. When this is fairly regular, cover with the blue bell-jar, and notice that the bubbling becomes slower after a short time. After about five minutes (take several readings during this time) take off the blue-jar and put on the red-orange one, taking records of the rate of bubbling as before, noting the increase in red as compared with blue light.

177. **Chlorophyll**. The green colouring matter of plants is a very complex substance, consisting of carbon, oxygen, hydrogen, nitrogen, and, according to some, also phosphorus. Its exact composition has not yet been definitely ascertained. It is sometimes stated that chlorophyll is not a simple colouring-matter or *pigment*, but a mixture of two pigments, one yellow, the other bluish green. There is no doubt now, however, that these are decomposition products of chlorophyll. Chlorophyll is very easily decomposed under the influence of bright light if oxygen is present, and these decomposition pigments are always present in chlorophyll as extracted from plants.

Two conditions, in addition to a suitable temperature, are necessary for the *formation* or development of chlorophyll: (*a*) the presence of light,* (*b*) a supply of iron in the food. If a plant is grown in darkness, it assumes a pale yellowish, sickly appearance. This is due to the fact that a yellowish colouring matter—**etiolin**—is developed in the corpuscles instead of chlorophyll. Such a plant is said to be ***etiolated***. Of course, a plant grown in darkness must have some reserve store of food material to draw upon, as, *e.g.*, a potato-tuber developing in darkness. Many examples of etiolated plants will readily occur to the mind of the student—*e.g.* celery, grass covered by a roller or a board. Typical

* In exceptional cases chlorophyll is developed in darkness (cotyledons of ferns and of a few seeds, *e.g.* Pine).

etiolated plants present many other peculiarities. Thus the internodes become very much elongated or "drawn out." For this reason the plants are called **"drawn plants."** This has an important biological significance. In this way there is a chance of shoots reaching the light, as, *e.g.*, in seedlings smothered by other plants. In etiolated plants, also, the leaves remain small and scaly, there is an enormous development of soft succulent parenchyma and a meagre formation of lignified tissue. Large leaves would be useless in darkness; we might say, therefore, that the plant devotes all its energy to the formation of long "internodes" which may be of use to it.

A yellowish, sickly condition is also established if there is no iron in the food, the plastids being colourless or containing etiolin. This condition, due to the want of iron, is called the **chlorotic** condition. It is to be carefully distinguished from the etiolated condition due to the absence of light. As soon as the plant is supplied with a *weak* solution of an iron salt, even if it is only applied to the leaves, chlorophyll is developed. Thus iron is necessary to the formation of chlorophyll, although it does not enter into its composition.

Chlorophyll can be extracted by means of alcohol, chloroform, etc. A solution of chlorophyll is fluorescent—it is green by transmitted light, red by reflected light. When a solution of chlorophyll is placed in the path of a beam of light, which is then passed through a prism, the spectrum is modified. Certain dark bands (absorption-bands) appear in the spectrum, more especially in the red region. This is because these particular rays have been absorbed by the chlorophyll. This leads us to the function discharged by chlorophyll. We have seen that the red rays are especially active in carbon-assimilation. We therefore conclude that chlorophyll is a colouring matter which, by absorbing certain rays of light, supplies the living protoplasm with the energy necessary for carrying on the chemical processes connected with carbon-assimilation.

Exp. 262. Grow seedlings, *e.g.* Cress or Mustard, in darkness, then place some of them in a good light, close to a window, and note the time required for the production of a distinct green colour. Place

the others in a dark part of the room, and when they have become green test the leaves for starch. These observations will show that (*a*) a green tinge, due to formation of chlorophyll, may be developed in an hour, or less, in good light; (*b*) light too weak for photosynthesis is strong enough for the production of chlorophyll.

Exp. 263. Grow in the same pot or box some seedlings of Pine and of Bean or Pea, keeping them in darkness, and compare the colour of the Pine-seedlings with that of the others.

Exp. 264. Place some etiolated seedlings (Cress, Mustard, Bean, etc.) in a bottle or small glass jar, cover with a glass plate, and set it in a larger jar half filled with water. Keep the water at 30° C. In a similar apparatus keep some of the seedlings in cool water, or water kept at 10° C., by adding bits of ice from time to time. Compare the depth of the green colour developed in the two sets of seedlings after an hour or two.

Exp. 265. To show that oxygen is necessary for formation of chlorophyll, fill a test-tube with water, invert it in water, and pass under its rim some etiolated Mustard seedlings. Though exposed to light, the seedlings do not become green, owing to lack of oxygen. Another method is to place heavier seedlings—*e.g.* Bean, Pea—in a glass jar and cover it with water. In each case similar etiolated seedlings should be placed on wet blotting paper at the bottom of a jar, whose mouth must of course be left open.

Exp. 266. Extract chlorophyll from green leaves (*e.g.* Bean, Grass; almost any leaves will do, but leathery ones should be chopped up) by boiling them in water, draining off the water, and covering the leaves with alcohol. Then place the dish containing the leaves and alcohol in the dark; light destroys the colouring matter in the solution. Filter the solution, and place it in a corked bottle.

Exp. 267. Notice the colour of the filtered extract by holding the bottle up to the light, and by holding it against a black surface; it is green by transmitted light, red by reflected light. Obtain a continuous spectrum on a screen by fastening on the lens of an optical lantern a card with a vertical slit, and holding a prism in the path of the light. Hold a test-tube of alcoholic chlorophyll-solution against the slit, and notice that the colours in several parts of the spectrum are replaced by dark bands. The most prominent dark band appears in the red part, but if the solution is strong enough other bands will be seen in the green and blue. Try the effect of interposing pieces of glass of various colours, or bottles containing solutions of dichromate of potash and of copper sulphate. In each case certain rays of light are stopped, that is, ***absorbed***, and ***the places of these rays in the spectrum are occupied by dark bands***, that is, by darkness. We see now that chlorophyll absorbs certain light-rays, allowing the rest to pass through it, and we may conclude that these absorbed rays in some way supply the energy which is needed in carrying on the work of photosynthesis. A direct-vision spectroscope (see Exp. 259) will show the absorption-

bands, especially that in the red part of the spectrum. A very useful additional piece of apparatus is a wedge-shaped bottle ("indigo prism") by means of which one can examine different thicknesses of the solution.

Exp. 268. Place some chlorophyll extract in a test-tube, dilute with a few drops of water, then add benzol, shake, and allow to settle. The benzol, which floats above the alcohol, dissolves out a bluish-green colouring-matter, leaving a yellow substance dissolved in the alcohol. These two pigments present in the extract can also be separated by using ether or olive oil instead of benzol. Find out, by using the spectroscope, or lantern and prism, which light-rays each of these substances absorbs.

Exp. 269. Fill three test-tubes with the extract, cork them, and place A in sunlight, B in diffused light, C in darkness. Carefully boil some extract in a fourth test-tube (D), and place it with A in sunlight. Notice, after a day's exposure, that A becomes brown, C is unchanged, while B and D are only slightly changed; the absence of oxygen in D hinders the destructive effect of light.

Exp. 270. Add some 10 per cent. solution of copper sulphate to some extract in two test-tubes; a copper compound is produced which is not red by reflected light, and which is not destroyed by light. Verify the latter point by placing one tube in sunlight, the other in darkness, in each case with a tube of ordinary leaf-extract for comparison.

178. **The Probable Stages in Photosynthesis.** Our knowledge of what actually occurs in the green leaf, exposed to light and sufficient warmth, and supplied with water and dissolved salts and with carbon dioxide, is by no means complete even now. It has been found that sugars are usually formed before starch, which is the first *visible* product of photosynthesis. Probably part of the sugar produced is converted into starch because the excess of sugar dissolved in the cell-sap would cause injury to the living substance (protoplasm); the starch, practically insoluble in water, is evidently a temporary storage substance, which is later removed after being converted back into sugar. But sugars are not the first organic substances formed in the process of photosynthesis. Sugars can be artificially built up by a process of synthesis, and one method is to first make a substance called formaldehyde. This substance (which is used for preserving food and for other purposes under the name "formalin") is a very simple carbohydrate, each of its molecules containing

1 atom of carbon, 2 atoms of hydrogen, and 1 of oxygen; it has therefore the same percentage composition as grape-sugar ($C_6H_{12}O_6$). Formaldehyde (CH_2O) has been detected in leaves, though it is poisonous and only occurs in very small quantities; moreover, starch is formed by a green plant when it is deprived of carbon dioxide, but supplied with a substance which readily yields formaldehyde. Probably the carbon dioxide (which passes in at the stomates and enters the cell-sap by diffusing in solution through the moist cell-wall) is broken up into carbon monoxide and oxygen ($CO_2 = CO + O$), while the water breaks up into hydrogen and oxygen ($H_2O = H_2 + O$). Then the carbon monoxide and hydrogen unite to make formaldehyde ($CO + H_2 = CH_2O$), while the oxygen-atoms (split off from the water and the carbon dioxide) are set free.

179. **Formation of Nitrogenous Substance.** The elaboration of nitrogenous substance is not so clearly understood as that of carbohydrates. The simplest process, leading to the formation of soluble nitrogenous compounds (*amides*, containing carbon, hydrogen, oxygen, and nitrogen), would be the inter-action of sugar and nitrate of potash, the chief products being an amide called asparagin (widely distributed in plants), and oxalate of potash. The latter, like oxalic acid itself, is poisonous, but it combines with the lime brought up in salts from the soil, forming oxalate of lime, which is insoluble in water, and therefore crystallises out and is rendered harmless. This is probably one source of the oxalate of lime which occurs so abundantly in crystals (fig. 50) in plant-tissues. These crystals are more abundant in leaves exposed to full sunlight than in shaded leaves, and in the green than in the not-green parts of variegated

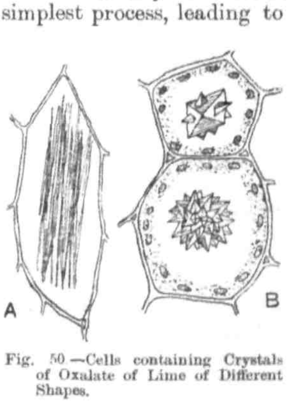

Fig. 50.—Cells containing Crystals of Oxalate of Lime of Different Shapes.

leaves. The disappearance of nitrate from leaves shows the same relation to light and to the presence or absence of chlorophyll as does the accumulation of oxalate of lime. Nitrate disappears from cut leaves in a few days, if they are exposed to light; in variegated leaves the nitrate disappears only from the green parts.

Exp. 271. Place young and old leaves of the same kind of plant (Horse-Chestnut, Elm, Hop, answer well, but others should be tried) in strong solution of chloral hydrate, which makes them transparent, and examine them with the microscope. Notice the greater abundance of oxalate crystals in the old as compared with the young leaves.

Exp. 272. Treat in the same way, examine with the microscope, and compare as regards the abundance of oxalate crystals, (1) leaves of Horse-Chestnut growing in full sunlight, and leaves from the shaded parts of the tree; (2) variegated leaves, *e.g.* Garden Geranium.

Exp. 273. The presence of nitrates in a leaf can be detected by cutting rather thick sections of the blade or the stalk, placing them on a glass slide, and adding a drop of diphenylamine sulphate; if nitrates are present, a deep blue colour appears (see Exp. 211). Cut off leaves (try various plants) and test them in this way; if they give the blue colour, set other leaves in the light with their stalks in water, and after a few days test again for nitrates. Test in the same way (1) the leaves of plants exposed to bright light, and compare with leaves of plants of the same species kept in deep shade, (2) variegated leaves of a plant exposed to bright light.

180. **Formation of Proteids.** Thus we have explained, as far as possible, the building up of soluble carbohydrates (sugars) and soluble nitrogenous compounds (amides) in the assimilating cells—chiefly the mesophyll cells of leaves. With the exception of what is used directly by the assimilating cells, the sugars and amides are transferred to the various parts of the plant. *All* living cells contain these soluble carbohydrates and nitrogenous compounds conveyed to them in the cell-sap. The living protoplasm makes use of these as food substance. Together with sulphur and phosphorus they are built up first of all into more complex (*proteid*) substances, and, finally, into protoplasm. This final elaboration is most active where rapid growth is taking place, *i.e.* at growing points.

One of the chief forms in which sulphur enters the plant is calcium sulphate. The sulphur is liberated, and thus

enabled to combine with the organic food substance, by the action of an organic acid. This acid appears in many cases to be oxalic acid. The calcium of the sulphate combines with the oxalic acid to form calcium oxalate.

181. **Use of the Metallic Elements.** So far, in connexion with these processes of elaboration, we have had little occasion to mention the metallic elements of the food material, with the exception of iron. Potassium, calcium, magnesium, and iron, do not enter into the composition of the living substance or of the cell-wall,* yet they are essential elements (Art. 131). Now we have seen that iron, although it does not enter into the composition of chlorophyll, is necessary for its formation. This gives us a hint as to the use of the other elements. It would seem that potassium in the same way is a necessary condition for the formation of carbohydrates, and that calcium and magnesium are necessary for the proper distribution of carbohydrates. Calcium is also of importance in the formation of more complex substances from carbohydrates, since it combines with, and thus makes harmless, the poisonous by-product (oxalic acid) which is formed in these processes.

182. **The Main Function of the Leaf** is to act as a laboratory for the manufacture of organic food from the carbon dioxide of the air and from the water absorbed by the roots. To carry out this process energy is necessary, and this energy is supplied by the light which the green chloroplastids absorb. During the process more complex substances such as sugar are formed, and a corresponding amount of energy is stored up in this manner. At the same time a volume of oxygen gas is liberated, equivalent to the amount of carbon dioxide assimilated. Hence green *plants exposed to sunlight tend to purify the air rendered foul by the breathing of animals.* When a plant is burnt, oxygen is consumed and mainly carbon dioxide and water produced, while the stored energy is liberated again almost entirely in the form of heat. This energy was stored up

* Calcium is present in the middle portion of thickened cell-walls, however.

The assimilation of carbon dioxide and the function of respiration are therefore, to a certain extent, antagonistic processes, the first involving a production of organic material, a consumption of carbon dioxide (and water), and a liberation of oxygen; the second, a consumption of organic material, a liberation of carbon dioxide, and a consumption of oxygen. The former process is twenty or thirty times more active than the latter in most healthy green organs exposed to bright light and supplied with sufficient carbon dioxide, so that these parts do not appear to respire during the daytime, or at least do not evolve any carbon dioxide. In darkness, however, it will be found that they respire only, as do the roots and all non-green part in both light and darkness.

The following experiments illustrate these points:

Exp. 274. Place a bunch of roots, or some carrots or onions sliced in half, or twenty to thirty germinating peas, in a jar, and after a day or two lower a lighted taper into the jar; what occurs?

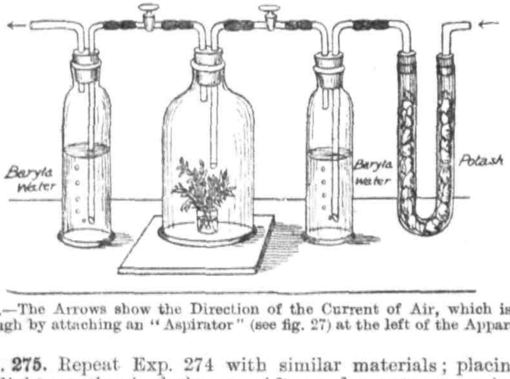

Fig. 51.—The Arrows show the Direction of the Current of Air, which is drawn through by attaching an "Aspirator" (see fig. 27) at the left of the Apparatus.

Exp. 275. Repeat Exp. 274 with similar materials; placing one jar in light, another in darkness. After a day or two pour in some lime-water or baryta-water, which will become quite milky, showing that carbon dioxide has been evolved in abundance. The same occurs when the bottles are exposed to bright light, as respiration continues almost unchecked.

Exp. 276. Suspend three healthy laurel leaves by threads from the well-fitting cork of a large bottle containing lime-water, and

expose them to bright light. After several hours the lime-water is still comparatively clear.* Cover the bottle with black cloth, and in a few hours the lime-water will become quite milky, owing to the respiration being no longer masked by the re-assimilation of the carbon dioxide it produces.

Exp. 277. Place some green leaves in a glass jar (fig. 51), through which a slow current of air is passed. This air is deprived of its carbon dioxide by the potash contained in the first tube, so that the lime-water or baryta-water in both (*a*) and (*b*) remains clear so long as the leaves are exposed to sunlight or very bright daylight, whereas if the bell-jar is covered with a black cloth, the liquid in (*a*) soon becomes turbid and milky.

184. **Transpiration**. Every one knows that a leaf, plucked from a plant, after a time becomes dry and withered. Have you noticed that wherever plants are enclosed by glass—*e.g.* in greenhouses, or bell-jars covering plants—moisture often collects on the glass? Does this moisture come from the moist earth, or from the plants, or from both? It is easy to show by experiment that a healthy and vigorous plant gives off large quantities of water-vapour, which escapes chiefly from the stomates on the leaves. This escape of water-vapour from a plant is called *transpiration*, and the current of water which passes from roots to leaves is called the *transpiration current* (see Ch. V.).

The amount of water conveyed upwards from the roots to the leaves is often very great, and the water usually flows upwards at from 6 in. to 6 ft. per hour in trees, or as much as 20 ft. per hour in climbers with long slender stems (*Cucurbita*, *Bryonia*, and tropical Lianas). Probably two causes at least are responsible for the upward flow of water, which of course takes place against the action of gravity. In the first place, the evaporation from the leaves tends to suck fresh supplies upwards to replace that removed by the air in the form of water-vapour, and in the second place, the roots and stem seem to exercise a pushing force (due to root-pressure, see Art. 129), driving water upwards. If the stem of a vine or similar plant is cut in spring, large quantities of watery sap escape from

* A little carbon dioxide may escape from the leaves, especially if they are allowed to shade one another, or if they are feebly illuminated.

the cut end attached to the roots,* and if a tube filled with mercury or water is attached to this cut end, by stout *rubber tubing*, the escaping sap will support a column of mercury several inches high, or one of water several feet in height. At night time the stomates close and transpiration is very much diminished. Absorption by the roots continues, however, and frequently so much water accumulates in the leaves that drops are forced out from them and from other parts also. Drops of water may often be seen in the early morning on certain Saxifrages and Grasses, and a similar exudation of water may be *artificially induced* by forcing water under pressure into a leafy branch (fig. 52).

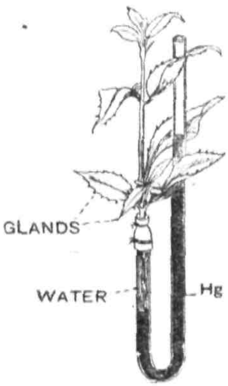

Fig. 52.—Mode of demonstrating the Excretion of Fluid Water from Leaves.

By pouring Mercury (Hg.) into the long arm of the tube the water in the short arm is forced under pressure into the stem and exudes in drops from the glands on the leaves.

A Sunflower, 3½ ft. high and with a surface of 5,600 square in., has been found in summer to exhale a pint of water a day, which is about a cubic millimetre from each square inch. Excessive and unchecked transpiration is, however, highly dangerous, and hence arises the importance of an impermeable cuticle, for it allows transpiration to be regulated by the opening and closing of the stomates. The guard-cells collapse and close the stomates in darkness, and also where there is a deficient supply of water, or when transpiration is too active. The leaf is unable to assimilate carbon dioxide in the absence of light, so that the stomates may close in darkness without detriment to the plant, and in this way unnecessary evaporation and its accompanying cooling effect are largely avoided.

* This only takes place when the plant is fully charged with water. Hence, in summer, no "bleeding" is shown, although if all the leaves are removed it may commence after a longer or shorter interval.

Exp. 278. Get any leaves with broad, thin blades and fairly long stalks—*e.g.* Lesser Celandine, Garden Geranium. Place them in bottles of red ink, with the cut lower end of the stalk dipping into the ink, and note the coloration of the veins. Cut a Grass shoot above the creeping stem, and try the same experiment, noticing the arrangement of the veins, as indicated by the red lines which appear in the leaves in a day or two.

Exp. 279. The sucking force exerted by the leaves can be demonstrated by attaching a leafy branch, cut under water, to a tube filled with water and dipping into a coloured solution. It will be found that the latter ascends the tube even when the latter is many feet in length.

Exp. 280. Get a branch of Willow in which the young leaves have become fully expanded, and attach it by means of a piece of stout indiarubber tubing to a glass tube about 9 in. long, with the end farthest from the branch bent at right angles for about 2 in. Arrange the branch vertically, the longer limb of the glass tube horizontally, and the short terminal part dipping into water tinged with red ink. It is best to cut the branch and attach the tubing under water in a large basin, so as to prevent the entrance into the stem of air-bubbles, which would diminish the flow of water. Lift the glass tube out of the water when the branch is fixed up, and notice that the coloured water soon begins to travel along the horizontal tube. This apparatus may be used to roughly measure the rate of the transpiration current. Ascertain whether the flow is different on bright and on dull days, and whether it is *influenced by opening door and window so as to cause a draught.* What is the effect of smearing the surfaces of the leaves with vaseline? On different branches, smear (1) the upper surfaces, (2) the lower surfaces, (3) both surfaces, of the leaves, and note the rate of the transpiration current in each case.

Exp. 281. By the aid of a simple piece of apparatus (fig. 53) and a weighing balance, the amount of water lost by a leafy stem can be determined, and at the same time it can be proved that the amount transpired is approximately the same as that absorbed by the roots. A plant is fixed by means of an air-tight indiarubber cork in a bottle filled with water. As water evaporates from the leaves and is absorbed by the roots, the level of the water in the graduated tube falls. This gives the amount absorbed by the roots, and on weighing the apparatus it will be found to correspond to the total amount lost by evaporation from the leaves and stem. Each of the larger divisions on the graduated tube corresponds to a cubic centimetre of water, so that when the roots have absorbed that amount the entire apparatus will have lost about 1 grm. in weight. The vertical tube attached to the side of the vessel, if not graduated by engraved lines, may have a scale drawn on a narrow strip of paper and fixed to it. The divisions should represent definite volumes, such as cubic centimetres. Fill the vessel

with water, replace the stopper firmly, and set aside for observation. *The volume of water becomes less, and the amount of loss may be* seen by observing the scale. Enter in a book the amount of loss in equal intervals of time, and note that it is less during darkness than in the light, and also that it varies with atmospheric conditions.

Exp. 282. Fix a Wallflower or large Bean seedling in the apparatus in fig. 53, and determine the amount of water lost under the *optimal conditions (i.e. in a warm, airy,* well-illuminated room), either by weighing at intervals, or by watching the attached register. Then remove all the leaves and cut out twice their area in thick note-paper, *to which add a piece the same length as the* stem and three times its breadth. Weigh all the pieces of paper together, and also a piece a foot square. The former weight divided by the latter will give the approximate surface area of the plant in square feet. From these data the average amount of water evaporated in a given time from a square inch of surface can be calculated.

Fig. 53.—Apparatus for estimating the absorption of Water by the Roots, and the loss by evaporation from the Leaves.

Exp. 283. Fix a long-stalked leaf (or the upper part of a herbaceous shoot, *e.g.* Dead Nettle) in a card, passing the leaf-stalk (or the stem) through a hole in the middle of the card and sealing it up with putty or plasticine. Place several cards, each with a leaf or shoot fixed into it, over tumblers nearly filled with water, and over each of these tumblers invert a dry empty tumbler, resting on the card. Notice the drops of water formed on the inside of each empty tumbler, by condensation of the water-vapour given off by the leaves. Ascertain whether any water-vapour is given off when (1) the upper surface, (2) the lower surface, of the leaf is smeared with vaseline to block the stomata.

Exp. 284. Get some cobalt chloride (nitrate or sulphate); make a solution (about 5 per cent.) in water, and soak some filter-papers or sheets of thin blotting paper in the solution. Dry the papers, and observe that they turn blue. Put a drop of water on one of the dried papers, or simply breathe on it, and notice the change in colour. These cobalt-papers afford a delicate test for water-vapour. Place a thin leaf between two cobalt papers, and keep them flat by placing between two pieces of glass. Notice which surface of the leaf gives off most water-vapour, as shown by the change of colour.

Exp. 285. Get a plant growing in a flower-pot; any plant with thin (not leathery) leaves will answer. Cover the soil with an india-rubber sheet to prevent evaporation, and balance the pot on a pair of scales. Observe the loss of weight by transpiration. Water the soil daily or every two days, replacing the indiarubber sheet each time, and ascertain whether the loss of weight differs on bright and on dull days, in light and in darkness.

Exp. 286. Another method is to use a small plant, *e.g.* a garden Geranium, growing in a tin fitted with a split cork through which passes a tube for watering. Make water-tight with plasticine, and note the loss of weight. Set beside the plant a vessel, *e.g.* a saucer containing water, and in order to compare the loss of water from the plant and from an equal area of water determine the area of the transpiring surface (as in Exp. 282) and that of the water in the saucer.

Exp. 287. Cut three healthy leaves of Indiarubber plant or of Rhododendron, plug the cut ends with plasticine, cover the *lower* surface of one (A) with vaseline, cover the *upper* surface of the second leaf (B) with vaseline, and leave the third (C) untouched except for the plug over the cut end. Tie a piece of wire or string to each leaf, weigh each leaf carefully, then hang them up near each other and weigh them each day. After several days the leaf whose stomates are blocked (A) will be still green and fresh, while the others will be more or less withered and brown.

185. **How Leaves are Protected.** We shall see later that young leaves nearly always have some mode of protection against loss of water; they are often covered with hairs, which may disappear as the leaf grows to its full size, or they may be bathed in a gummy or resinous liquid; or they may be rolled or folded up at first. These protective arrangements are especially necessary when the leaf is young and its tissues tender and liable to lose water readily, or to be injured by strong light or by cold. In many plants the mature leaves show similar protective arrangements, which are especially marked in plants which grow in places where they are exposed to strong light, to drying winds, cold, and other injurious conditions, such as a scanty or precarious supply of water. Most evergreen plants have a thick cuticle, or a layer of clear cells below the upper epidermis, and the stomates are often sunk below the level of the epidermis. Other arrangements by which transpiration is diminished is the rolling up of the leaf (Heather, etc.), or a thick covering of hairs (Woolly

Mullein, etc.), especially on the lower surface of the leaf, to which the stomates are restricted in most firm, thick, or leathery leaves. It is easy to show that a dense covering of hairs checks the rate of transpiration, by repeating Exp. 280 or 281 after fastening to each leaf a piece of cotton-wool so as to cover the lower surface of the leaf, or both surfaces, and noting the effect this has on the rate at which the leaves give off water-vapour. The effect of rolling can be observed by folding the leaf or rolling it up longitudinally to form a tube with the lower epidermis on the inside and tying it with thread, and noting the reduced rate of transpiration. Many leaves also have their surface covered with waxy matter or "bloom," so that they are not wetted by rain. This is well shown by the Broad Bean, Tropaeolum, Cabbage, and many other plants. The "bloom" not only prevents water from entering the leaf and blocking up the air-spaces, but also helps in reducing transpiration; if the "bloom" is removed from an India-rubber Plant leaf by sponging its surface with warm water, the leaf will lose more water than one with the bloom untouched.*

186. **Summary of Chief Functions of Green Leaf.** These functions may be thus briefly summarised:

(1) Leaves are the respiratory organs of the plant, since they allow a free exchange of gases with the atmosphere by means of their stomates.

(2) The chlorophyll of the leaf, which, as we have proved, is itself formed only under the influence of light, has the power, under this same influence, of decomposing the carbonic acid gas of the atmosphere, and of building up with the carbon so obtained, together with the dissolved mineral substances absorbed by the roots from the soil, the sugar, starch, and other organic compounds of the plant. Some of the material thus formed in the leaves is transmitted to the stem and root in a soluble state, and often stored in these organs in large quantities.

* The experiments suggested in this article should be made by the student. The adaptation of plants to their environment is dealt with in Ch. IX.

(3) Water absorbed by the roots passes up the stem to the leaves, where a large proportion of it is lost by evaporation through the stomates. Water lost by evaporation in this way is being continually replenished by the roots, and thus there is a steady upward current by means of which new mineral matter is constantly supplied. The stomates are reduced in size by the collapse of the guard-cells when "transpiration" is too active, and when the water supply in the soil is deficient. They also close in darkness, when less food is needed; and by so doing they also prevent the plant from becoming too cold, for evaporation is always accompanied by a reduction in temperature. In brief, therefore, the leaf primarily acts as an organ for absorbing radiant energy, and storing it up as potential energy in the form of food. It also promotes gaseous exchange in general, and usually forms the main transpiring surface, although transpiration, like respiration, is one of its subsidiary functions.

Some of the additional functions performed by the leaves of certain plants will be dealt with in later chapters.

187. **Forms of Leaves**. Before quitting the study of leaves we must observe a number of their general characters—their variety of form, arrangement of veins, etc.* In order to do this we shall have to examine a considerable number, and to this end the student should take a country ramble, supplied with a book for notes and sketches, and a lens to assist his observations. We must necessarily be very brief in dealing with this part of our subject, and our instructions must be accepted as merely suggestive, and by no means exhaustive.

A typical leaf consists of a basal more or less sheathing portion, called the leaf-sheath or leaf-base, a stalk or petiole, and a flattened terminal portion, the blade or lamina. The leaf-sheath is usually simply the flattened basal portion of the petiole, but in most grasses it is of considerable size, and ensheaths the stem for some distance above the node from which it arises.

* The different ways in which leaves adapt themselves to the nature of their surroundings will be dealt with in Ch. IX.

A sheathing leaf-base is frequently absent, but is especially well developed in such plants as Buttercups, Grasses, Docks, Umbellifers. The mode of insertion of different leaves exhibits a wide range of variation, but they always arise from the shoot or its branches. The so-called "radical" leaves simply arise from a very short stem (Primrose, Dandelion). In some cases the base of the leaf is *decurrent*, and forms membranous outgrowths on the main axis, while it may even unite around the stem so as to form a *perfoliate* leaf.

Occasionally the leaf-base becomes thick and fleshy, and forms an irritable organ known as the *pulvinus*, which reacts to light in such a manner as to place the lamina under the best possible conditions of illumination. This is possible owing to the fact that the pulvinus retains the power of growth for some time after that of the rest of the leaf has ceased, as can easily be observed by watching kidney-beans and altering the position of the stem from time to time. In some plants the pulvinus responds quite rapidly to changes in the direction and intensity of the light. Thus the compound leaf of the Sensitive Plant (fig. 54) places itself at right angles to the light falling upon it. Each leaflet, however, has a pulvinus of its own, and when the leaf is exposed to strong sunlight these pulvini curve in such a manner as to cause the leaflets to fold together in a few minutes, before they have time to be injuriously affected. At nighttime, also, the leaflets fold together and go to sleep, as it were, while the whole leaf sinks downwards. In this position the leaf loses less water by evaporation, and remains warmer than it would be if expanded. The first movement

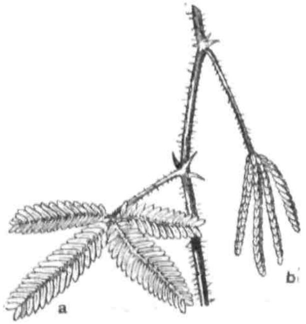

Fig. 54.—Leaves of Mimosa Pudica (the Sensitive Plant).
a, Expanded day position; b, Drooping folded night position.

is due to the action of strong light, the second to the absence of light, and their importance and utility to the plant are sufficiently obvious.

Exp. 288. Observe the leaves of a living Scarlet Runner. Notice that they are compound, and that at the base of the main petiole is a dark green swollen pulvinus. Bend the stem so that the lower surface of a leaf is uppermost, and notice at the end of two or three days that the pulvinus has bent until the leaf assumes its normal position, the individual leaflets adjusting themselves in a similar manner.

Exp. 289. Get a small Sensitive Plant in a pot, and notice that when the pot is shaken, the main petioles move downwards, the secondary petioles move closer together, and the leaflets close up in pairs. Touch the pulvinus of a leaflet or of the whole leaf (fig. 54), *and notice the movements thus induced. Observe that it is the* lower, not the upper, surface of each pulvinus which is irritable. Hold a lighted match a few inches below a pair of terminal leaflets, and note the order in which the parts of the leaf move, in response to the stimulus of heat. Similar experiments should be made with the compound leaf of the Wood Sorrel.

Exp. 290. Show that "sleep-movements" may be induced in the daytime by covering a Clover plant (growing out of doors or in a pot) with an opaque vessel, and heaping soil round the rim to exclude all light.

188. **Stipules.** Very commonly wing-like outgrowths arise from the base of the petiole, and frequently these simply assume the form of lateral outgrowths of the leaf-base. The organs in question are known as **stipules,** although they cannot always be sharply defined. The stipules vary much in size, form, and colour. When they are quite small, dry, pale, and membranous they are usually functionless, but frequently they form large coloured protective bud-scales (Magnolia, Fig, Beech), and fall when the leaves unfold. In the garden Acacia (*Robinia*) the stipules are metamorphosed into spines, and in *Smilax* they become tendrils. In some peas (*Lathyrus aphaca*) they are large and green, and actually take the place and function of the foliage-leaves, which are modified into tendrils (fig. 55). Stipules are often relatively large while the leaf is young, and in such cases they serve as a protection to the young buds or young foliage, frequently falling off as the leaf expands. When present upon adult leaves, the stipules

aid in the production of organic food if they are green, and they may also help to lead away rain water from the plant so that it can dry rapidly, or to direct the water to those

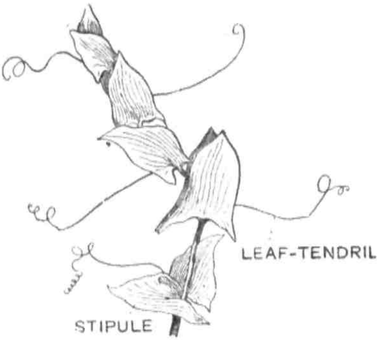

Fig. 55.—Lathyrus aphaca.

regions of the soil where the absorptive organs (root-hairs) are most abundant.

Sometimes the margins of the two stipules cohere between the leaf and stem, apparently forming a single axillary stipule. In the Rhubarb family (Polygonaceae) they join to form a tube (ochrea) enclosing the stem for a short distance above its junction with the leaf.

The basal portion of a grass leaf ensheaths the stem for some distance, and just between the stem and the base of the free portion of the leaf there is a small crescentic scale on the upper surface of the latter. This scale is termed the *ligule.*

189. **Petiole.** Note that while some leaves have a distinct stalk (*petiole*), in others the lamina extends down to the stem of the plant. The latter are called *sessile leaves.*

The petiole is usually directly prolonged into the lamina as the midrib, but in the Garden Nasturtium (*Tropaeolum*) and in the Pennywort (*Cotyledon*) the projecting leaf-bases unite on the opposite side of the petiole, so that the stalk is

attached to the middle of the under-surface (peltate leaf). A transition stage is shown by the leaves of the Water-Lily. The petiole may be winged, and it is usually cylindrical or semi-cylindrical, being frequently flat or even grooved on the upper surface. The petiole is a special secondary structure developed in order to enable the lamina to expose itself to suitable illumination, and it is not always present. It contains strands of vascular tissue, which are continued into the lamina as the branching veins of the leaf. There is usually a large median vein, lying above a prominent midrib, although in other cases a number of veins of equal size enter the leaf from the petiole. In Woody Nightshade (fig. 70), Garden Nasturtium, and Clematis, the petiole has the power of coiling around supports, and hence it acts as a tendril in spite of the presence of the lamina or blade.

190. **Veins.** The veins are simply conducting bundles which run outwards from the stem into each leaf, and undergo considerable branching throughout the substance of the lamina. The larger veins usually project as ridges on the under-surface, but the smaller veinlets are buried in the tissue of the leaf. The arrangement of the smaller veinlets and the number of the larger veins differ in different leaves. This is what is termed the venation of the leaf. Note that the leaves of all grasses, orchids, flags, wild hyacinths, and daffodils have all their principal veins running parallel through the entire length, and that these leaves are more or less elongated and blade-like. The leaves of most of our trees and herbs, however, have their principal veins branching off from the midrib on either side, while the smaller ones form a delicate network such as we observed in the bean leaf. The former arrangement (*parallel venation*) is characteristic of Monocotyledons, the latter (*reticulate venation*) of Dicotyledons (but also found in some Monocotyledons, *e.g.* Arum, Black Bryony). If leaves are allowed to decay in water until the softer parts can be brushed away, skeletons of the harder parts can be obtained which directly exhibit the venation, but in most cases it is sufficient to hold up the leaf to the light to render the smaller veins plainly visible.

191. **Simple and Compound Leaves.** Some leaves are *simple*; that is, their flat part or *lamina* is not divided into distinct portions, though they may be very deeply divided. Such is the case with the leaves of the Oak, Hazel, Ivy, Dandelion, etc. These simple leaves exhibit a great variety of form, and the student should make a series of drawings illustrating the more typical as well as some very exceptional shapes.

In compound leaves, of which we have already seen an example in the Bean, the lamina is divided into distinct parts called leaflets, which may be arranged in opposite pairs along the central stalk as in the Rose and the Pea, or may all radiate from one point of the stalk as in the Horse-Chestnut.

The outline of the lamina assumes a great variety of forms, and special technical terms are given to the more strongly marked and more commonly occurring of these. It must, however, be remembered that all gradations exist between leaves of widely different shape, and since no general principles are involved in the application of these terms, they need not be discussed here. Very frequently the margin of the leaf is deeply indented, and if the indentations are regularly arranged, and are so deep as to reach the midrib, a compound leaf composed of a series of leaflets is produced. This will be *pinnate* or *palmate*, according to the arrangement of the main veins (fig. 56), for the incisions will naturally fall between these.

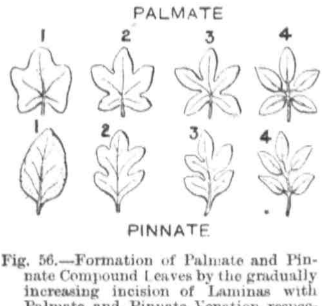

Fig. 56.—Formation of Palmate and Pinnate Compound Leaves by the gradually increasing incision of Laminas with Palmate and Pinnate Venation respectively.

Compare the simple leaves of the Ivy and the Beech, both of which are of the net-veined type. Note that in the former the principal veins all radiate from one point at the base, while in the latter they branch off from the midrib almost throughout its length. Now, since a com-

pound leaf is produced by the division of the lamina between the principal veins, it is easy to see that the former, so divided, would produce a compound leaf with radiating leaflets. Such an arrangement of veins is termed *palmate venation*, and the leaves, both simple and compound, more or less divided in this fashion, are called *palmate leaves*. The arrangement of veins in the second instance is called *pinnate venation*, and by the incision of the lamina a *pinnate leaf* is produced, which, in the case of the compound leaf, would have opposite leaflets.

A compound or segmented leaf is easily distinguished, even by beginners, from a stem bearing leaves because of the absence of any apical bud or growing point, and by the fact that a bud occurs in the axil of the main petiole, whereas there are no buds in the axils of the leaflets.

192. **Shapes of Leaf-Blades.** The following list includes the principal shapes:

(1) **Blade broadest near the base**—*e.g.* **cordate** (heart-shaped), **sagittate** (arrow-head-shaped), **reniform** (kidney-shaped), **ovate** (egg-shaped), **lanceolate** (lance-head-shaped, much longer than broad, tapering to pointed tip).

(2) **Blade broadest near the tip**—*e.g.* **obcordate, obovate, oblanceolate** (outline as in cordate, ovate, and lanceolate, but with the narrow end at the base), **spathulate** (spoon-shaped, *e.g.* Daisy).

(3) **Blade as broad in the middle as anywhere else**—*e.g.* long narrow forms, as **acicular** (needle-shaped), **linear** (long and narrow, with parallel margins), **cylindrical**; and rounded forms, as **orbicular** (circular), **elliptical, oval, peltate** (shield-like, blade nearly circular, but with stalk near the middle of lower surface).

193. **Leaf-Margin.** Next observe the different kinds of margins possessed by leaves. Some are plain or *entire* (Privet and Wallflower); while others have teeth which either stand out at right angles to the general direction of the edge (Holly), or, as is more commonly the case, point in one direction, more towards the apex of the leaf, and thus resemble the teeth of a saw (Rose, Dead-Nettle, Stinging-Nettle, etc.). Note also the hairy margin of the Beech leaf, the wavy or sinuate margin of the Oak, the irregularly toothed edge of the Dandelion, the spiny margin of the Holly, and various other modifications of leaf margins, all of which should be drawn from nature.

194. **Leaf-Arrangement**. Observations should also be made of the different ways in which the leaves are arranged on the stem. Note the leaves of the Bed-Straw and of the Goose-Grass, arranged in "whorls"* around the nodes of the stem, and the pairs of opposite leaves in the Stitch-Wort, Chickweed and Sycamore; and note that in cases where the leaves are placed either in pairs or in "whorls" of more than two, each leaf arises vertically over the gap formed by leaves of the pair or "whorl" below it.

In most cases the leaves are arranged in such a manner as to form a spiral. The nature of the spiral may be easily determined by tying a piece of cotton to the base of a leaf, and carrying it in order to the bases of the leaves above, twisting it around each one. Suppose, for instance, we do this in the case of a young shoot of the Hazel; we find that each leaf is one-third round the stem as compared with the one below it, and consequently the fourth leaf is vertically above the first, being the starting-leaf of a second turn of the spiral.

195. "**Leaf-Mosaics.**" Instead of giving details here about the various modes of arrangement of leaves on the stem, we will call attention to the *reasons* why leaves have such varied arrangements and shapes. The main fact to remember is that leaves require to catch as much sunlight as possible, especially in a country like ours, where the number of hours of sunshine is rather scanty. The south coast of England only gets about 1,600 hours of sunshine annually, and in the rest of Britain the number is usually far below this. In many British plants the leaves tend to fit together like the bits of glass in a mosaic, so as to avoid shading each other and to lose as little sunlight as possible. This tendency is easily seen in (1) plants whose leaves are crowded together and form a rosette close to the ground—*e.g.* Daisy, Hawkweed, Plantain, London Pride; (2) many plants with whorled leaves—*e.g.* Woodruff; (3) twigs of many trees—*e.g.* Horse Chestnut, Beech, Elm, Lime; (4) twigs of plants which creep along a wall or bank—*e.g.* Ivy. In Labiates (*e.g.* Dead-Nettle) and Stinging-Nettles, the

* How many leaves in each "whorl" have branches in their axils? Some of the apparent leaves are really stipules.

lower leaves have broader blades and longer stalks than the upper ones. You should notice, and try to account for, these and many other arrangements, remembering that besides the tendency to catch as much light as possible, the shapes of leaves are often influenced by other causes—*e.g.* the necessity to withstand high winds, to carry away rain which falls on the blade, to catch the light when growing in dense masses (*e.g.* grasses and plants growing among them in fields). This interesting subject can only be studied by personal observation; any field, wood, hedgerow, or garden, will afford abundant material to illustrate the points here mentioned, and to show how the arrangement and shapes of leaves help plants in the struggle for light and air, which is, of course, keenest where plants are growing in crowded fields or hedgerows. For further details, see Scott Elliot's *Nature Studies* and Lubbock's *Flowers, Fruits, and Leaves.*

196. **Decay and Fall of the Leaf.** Leaves which fall before the vegetative season is over are *caducous*; *deciduous*, if they fall at the end of each season, as in most cases of our forest trees; *persistent*, if they remain on the plant for more than one season, as in evergreens. The leaves of such plants as Grasses, Lilies, Irises, etc., simply wither on the stem, but in most trees the fall of the leaf at the end of the vegetative season is brought about by the plant itself. When the activity of such leaves is nearly over, and they have been partly emptied of the food-substances they contain, a layer of cork-tissue forms across the base of the leaf, and by interposing an impermeable layer between the leaf and the stem, cuts off from the former all supplies of water and mineral salts. The fall of the leaf is usually hastened by the formation of a special *abscission layer* of cells just outside the cork. This layer readily disintegrates and thus separates the leaf from the stem, leaving the scar of attachment of the leaf already healed and covered with cork. A similar leaf-fall sometimes occurs during hot, dry, summer months when the supply of water is deficient, for by sacrificing a portion of its leaves the plant may be able to provide the remaining ones with sufficient water

to keep them living. In both cases the process is a vital one due to the activity of the living plant, for if a branch is killed by means of hot water, the leaves wither upon it without being shed.

Whenever the plant wishes to throw off certain organs at a definite time (petals and other floral parts after fertilisation; fruits and seeds when ripened) it makes use of similar abscission layers, for by this means it can delay *or accelerate the fall of the particular organ according to* circumstances.

QUESTIONS ON CHAPTER IV.

1. What differences exist between the cotyledons and the foliage-leaves of the Broad Bean? How may these differences be accounted for?

2. How could you prove that a leaf has air-spaces inside it and air-pores on its surface?

3. *Describe the structure of a typical foliage-leaf.*

4. How could you prove that a green leaf makes food when exposed to light?

5. Under what conditions is starch formed in the foliage-leaves of an ordinary land plant? Give experiments in proof of each statement.

6. What is a stomate, and how does it work? Why do people often syringe or sponge the leaves of plants grown indoors or beside a dusty road?

7. To what substance do the green parts of plants owe their colour? State and explain the nature of the work which only the green parts of plants are able to perform.

8. Explain how it is that a green plant cannot carry on its nutrition in darkness.

9. What constituent of plant-food is obtained from the atmosphere? What changes do plants affect in it? Describe an experiment to demonstrate this.

10. What is meant by the term Photosynthesis? What is the first *visible* result of this process, and how would you detect it in a leaf?

11. What gases would you expect to find in the air of a closed glass vessel exposed to light before and after leaving a green plant within it? State the relative quantity of the various gases, and how the presence of each can be detected. How could you measure the quantity of each gas?

12. Two leaves, while still attached to the plant, are kept in the dark for twenty-four hours; then one is exposed to sunlight for same hours, while the other still remains in the dark. By what foter-treatment would you distinguish between the two? Explain

your exact procedure and the reasoning on which you base your conclusions.

13. Explain as fully as you can how it is that the guard-cells of a stoma are enabled to alter the size of the aperture between them.

14. What is the importance of carbon to a plant? From what source does a green plant get its carbon, and how is it assimilated?

15. What do you consider the essential characters of the foliage leaves of a green plant—*i.e.* the characters in which all or nearly all leaves you know agree? How are these features of leaves of service to the plant?

16. What are the "veins" of a leaf? What are their uses? How would you show, by experiment, the correctness of your statements?

17. On what law does the intensity of light depend? How does light-intensity affect Photosynthesis?

18. What is meant by Refraction? What is a prism, and how could you prove by its use that white light consists of rays having different colours?

19. Describe the continuous Spectrum. How is the appearance of the spectrum affected by an extract of chlorophyll being placed between the prism and the screen on which the spectrum is received?

20. What is the function of Chlorophyll? Under what conditions is it formed, and how does it occur in the plant?

21. Of what substance do the crystals found in plant-cells usually consist? Under what circumstances are these crystals formed?

22. Give an account of the process of transpiration. By what means does the plant regulate its transpiration?

23. If on a warm sunny day a plant growing in a pot had become limp and "wilted," how could you restore it to its normal condition without watering it in any way?

24. Why does the inside of a Cabbage consist of lighter coloured, thicker, and more succulent leaves than the outside?

25. Explain why it is that plants droop on a hot day, and recover their freshness in the evening.

26. Describe experiments you have made on Transpiration, and explain how the rate of transpiration is affected under different conditions.

27. Mention the different forms which may be assumed by the stipules of plants. Give one example of such, and state the special use of the stipules in each case.

28. How are the leaves arrayed on the twigs of a Horse-Chestnut (or a Sycamore)? Point out any special adaptations which bring about the full exposure of the leaves to the light.

29. Explain how it is that dandelions and plantains are able to live so successfully as weeds in a lawn.

30. Trace the path followed by a particle of water, from its entrance into the root to its exit, as vapour, from the leaf.

CHAPTER V.

STEMS AND THEIR WORK.

READ again the parts of Chapter I. which deal with the stem of the Broad Bean, and recall the observations and experiments you have made on various plants, which suggest the main functions of the stem. We have studied the leaf and its chief functions first, because (as you will see more clearly as you proceed with your work on plant biology) the work of the leaf is of the highest importance. As we have seen, the green leaf manufactures organic food from the raw materials which it takes from the air and from the soil, and it also serves as the chief means by which the air within the plant communicates with the atmosphere, and by which the gaseous exchanges concerned in respiration and transpiration are carried on. What are the main functions of the stem?

Exp. 291. Pull up some Broad Bean seedlings (or other seedlings or plants) and let them lie on the table. Notice that the leaves soon show signs of withering, through loss of water. Pick some leaves from the stem, and notice that they soon begin to wither. This shows that the water absorbed by the root passes up the stem to the leaves.

Exp. 292. Take a Bean seedling which has been pulled up and allowed to lie for some time, till its leaves have begun to wither. Place the seedling with its stem under water coloured with red ink, then cut across the stem under the coloured water. Take the stem out and notice that the water has run up, in the bundles, for some distance. This shows that when the leaves are transpiring and the roots are not absorbing enough water, there is a "negative pressure" in the water-carrying channels, so that when the stem is cut under the coloured water, the liquid rushes in.

Read again the portions of Chapter IV. dealing with Transpiration.

Exp. 293. Repeat Exps. 166-9, 173-8, and observe that the shoot of a Bean seedling grows towards light, away from the earth, and away from moisture. Compare its responses to the stimuli of light, gravity, and moisture with those made by the root

to the same stimuli. Also note that the growth in length of the young shoot and the curvatures it makes in response to the stimuli of light, etc., are confined to the region below the growing-point. To prove this, mark the plumule in the same way as the root in Exp. 173.

Exp. 294. Place whole plants, or seedlings, or cut twigs, into water coloured with red ink, set them where the conditions are favourable for transpiration, and after an hour or so cut across the stem a few *inches above the level of the coloured water.* If the latter has risen in the stem, trace it upwards by means of successive cuts, then replace the plant in the liquid, and after a time notice its appearance in the leaves, as shown by the colouring of the veins.

Exp. 295. Make thin cross-sections and longitudinal sections of all the plants you use in Exp. 294. In most cases notice that the bundles are arranged in a single ring; this arrangement is found in most Dicotyledons. In Grasses, Lilies, and other Monocotyledons, the red-stained bundles will be seen to be scattered through the stem. *Notice that in most cases only the inner part of each bundle* is stained. In Vegetable Marrow or Cucumber the bundles are in a double ring, and here the central part of each bundle is stained.

Exp. 296. Place a twig of a tree—*e.g.* Oak, Beech, Elm, or any other hard woody plant—in the coloured water, and when the leaf-veins become coloured, cut across the stem, starting in this case at the top where the stem is soft and green. At the top notice that the bundles are separate; but as we pass downwards, making successive cuts, the bundles appear to fuse and form a continuous ring.

Exp. 297. Cut two twigs of a woody plant—*e.g.* Willow—about equal as regards length and the number of leaves. Cut round one *of the twigs, a few inches from the lower end, as far in as the hard* woody part, and remove from the lower part of the stem the whole of the soft outer tissue. Leave the other twig uninjured, and set both twigs into red ink. Notice that the removal of the outer tissue makes little or no difference as regards the rise of the red ink in the stem and its appearance in the veins of the leaves.

197. **The Conducting Channels of the Stem.**—The foregoing experiments show (1) that one function of the stem is to carry water from the roots to the upper parts of the plant, and (2) that the water travels through the inner portion of each bundle when the bundles are separate, and through the hard woody part of a stem when the bundles are joined to form a continuous cylinder. Through what channels do the organic substances produced in the leaves travel to other parts of the plant? If these also travel along the bundles, they must pass through the soft outer tissue in the case of a woody stem; and in that of a stem

with separate bundles, these substances must pass either *through the part of each bundle which was not stained by* the red ink or else through the other tissue of the stem, or by both routes. Before considering this question, we must know more about the structure of the stem; but the following experiments will give a clue as to the paths by which *leaf-manufactured food travels.*

Exp. 298. Place a Bean seedling or a garden Nasturtium (try various other plants) in darkness for a few days, then remove some leaves and test them for sugar by boiling them in Fehling's solution. There will be little or no red coloration, showing that sugar is absent, or nearly so. Expose the plant to sunlight for several hours, then place it in darkness (after having tested some leaves, or parts of leaves, for starch), and after a time test some leaves for sugar, which will be indicated by the red colour produced around the veins. *If the presence of sugar is* detected in this way in the leaf-blade, test *sections of the leaf-stalk at different levels, to* find out by what paths the sugar travels *towards the stem. Also test sections of the* stem itself. By careful use of Fehling's test, it *is easy to prove that the sugar travels in the* leaf itself along the tissue surrounding the veins (bundles), and in the stem it is to be found in the ground tissue in which the bundles are embedded.

Fig. 57. — A Ringed Branch of a Willow sprouting in Water.

Exp. 299. Make two cuts round the lower part of a Willow twig, about an inch apart, and remove the soft outer tissue of the stem between these cuts, so as to leave only the hard woody portion of the stem for this distance. Then set the twig in water (which should be changed every day) or in culture-solution, and notice that it begins to sprout after a few days (fig. 57). Below the injury the development of buds and new roots takes place but slowly, whereas above it new roots are rapidly formed and nourished by food conveyed from the upper parts of the branch by the tissue lying on the outer side of the wood. This experiment usually succeeds best in spring or early summer. Later in the year it is advisable to remove the leaves in order to diminish the loss of water, since there are no roots on the cutting to keep up the supply of water. The rapid development of buds and the formation of roots above the ringed part show that food passes down chiefly through the soft outer region of the stem.

198. **Chief Functions of the Stem.** The leaves must be exposed to air and light in order to carry on their work of food-making, and in this work they require supplies of water containing dissolved salts. The food made by the leaves has to be carried to other parts of the plant which are living and growing or acting as storage-organs. The roots, having no chlorophyll and not being exposed to light, cannot, of course, carry on photosynthesis, and must therefore be supplied with organic food made in the leaves.

From these considerations, and from the results of our simple experiments, it is clear that the ordinary functions of a stem are (1) to bear the leaves and help in spreading them out to light and air; (2) to convey water with dissolved salts from the roots to leaves and other parts of the shoot; (3) to carry organic food from the leaves to other parts. These are the primary functions of the ordinary stem, but in addition to this stems often have to take on special functions. Thus they may serve as organs of vegetative propagation, as store-places of nourishment, or as protective organs. Stem-structures assume an immense variety of forms, according to their special adaptations. Some (*e.g.* Foxglove, Sunflower, Lily) grow straight up, and are self-supporting; they are said to be "**erect.**" This is the typical form of stem. Others are **weak stems,** incapable of themselves of growing erect. Most stems are aerial, but many are buried in the soil, and are called underground stems. Some are herbaceous; others are woody. Most woody plants form shrubs or trees, and are **perennial**—*i.e.* persist for a number of years. Herbaceous plants may be **annuals,** living only during one season, and dying down in the autumn; others are **biennial** (*e.g.* the turnip), living during two seasons. In the first year they produce only vegetative shoots; in the second, flowers, fruits, and seeds. Many herbaceous plants, however, which die down in the autumn perennate by means of their underground stems.

199. **Structure of the Stem.** In Dicotyledons, both in herbaceous stems and in woody stems when young, isolated bundles run through the stem, forming a hollow cylinder (a ring, as seen in cross-section). In Monocotyledons the

bundles are scattered through the ground-tissue of the stem. This is because in the former case the vascular strands which run into the stem from the leaves remain near the surface, ultimately joining strands from other leaves and increasing in size, whereas in Monocotyledons the strands from each leaf run deep into the stem and curve outwards lower down, tapering away as they do so

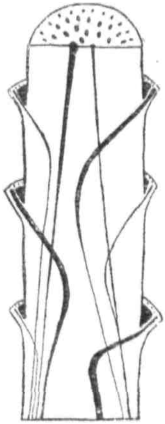

Fig. 58. — Longitudinal Course of the Bundles in a Monocotyledonous Stem.

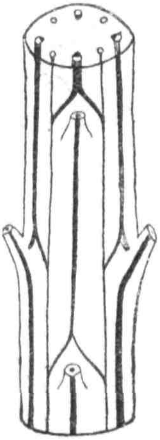

Fig. 59 —Course of the Bundles in Stem of a Dicotyledon.

(fig. 58). Hence the strands on the outside of a transverse section are in this case smaller than the central ones, whereas in the Dicotyledon the smaller strands alternate with the larger ones (fig. 59).

It is important to realise that the bundles in the stem are continuous with the veins of the leaves on one hand and with the vascular cylinder of the root on the other.

Exp. 300. Soak the stem of a Dead Nettle (try other herbaceous Dicotyledons) for two days in dilute potash and then for two days in dilute nitric acid. Brush and scrape away the softer parts, leaving a skeleton of the vascular tissue. Note the way in which the bundles from the upper leaves join on to those from the lower

leaves. (Each median bundle splits into two in the stem before doing so.)

Exp. 301. Another method of showing that the vascular bundles (veins) of the leaf are continuous with those in the stem is to cut thick longitudinal slices through the stem and the bases of the leaves, and place the slices in caustic potash.

Exp. 302. To observe the continuity between the bundles of the stem and those of the root, split a Bean seedling longitudinally in the part where stem and root meet, and treat with caustic potash or aniline chloride.

Exp. 303. The Vegetable Marrow (or the Cucumber) is one of the most suitable plants in which to study the tissues of the stem. Cut across the middle of several "internodes" in the older parts of the shoot, and in each piece thus obtained notice that (1) the "node" gives off a leaf, a special climbing organ (tendril), and usually either a leafy branch or a flowering branch, or both; (2) the internode is hollow, so that the stem forms a tube, with (usually) five ridges, and furrows alternating with these, on both the outer and the inner sides; (3) each ridge (both outer and inner) is traversed by a bundle, so that the bundles are arranged in two rings. Scrape gently the outer surface of the stem, and remove part of the epidermis or skin, which is thin and colourless and bears hairs, some of them large and prickly. Notice the soft tissue which lies between the bundles; this is the ground tissue, or *parenchyma*, and its cells can easily be seen with a lens. After removing the epidermis, scrape away the soft tissue which lies below it, and notice the hard tissue, which forms a wavy tube around the stem, outside of the bundles. Slit a piece of stem by two longitudinal cuts, and by scraping isolate a strip of this hard tissue, or *sclerenchyma*. Bend it, pull it by the two ends, and try to split it; notice that it is easily split longitudinally, less easily bent, and rather difficult to break by pulling at the ends. This hard tissue, then, is fibrous and fairly flexible, but very strong, and it gives mechanical support to the stem; it is really a part of the ground-tissue, which has become fibrous and hard.

Exp. 304. Now examine the bundles which are embedded in the soft ground-tissue within the sheath or tube of hard tissue. Notice in each bundle (1) a whitish hard portion, consisting chiefly of tubes of various sizes, and occupying the centre of the bundle; (2) two greenish soft portions on the inner and outer sides of the hard portion. Place a piece of the living shoot with its cut end dipping into red ink, and notice that the ink rises in the middle portion of each bundle. This portion is the *wood*, and the tubes it contains are the *vessels*, which carry water upwards from the root. Split a long piece of stem so as to get a strip containing a single bundle; put one end into a glass of water and blow through the other, noting the air which escapes in bubbles after passing through the vessels. This shows that the vessels are long, open tubes.

Exp. 305. Next cut across a fresh piece of stem with a dry knife or razor, and notice the juice which oozes out of the soft greenish outer and inner portions of each bundle. These portions are the *bast*,* and they also consist chiefly of tubes; but the bast-tubes, instead of carrying water up the stem as the wood-tubes (vessels) do, carry organic food-substances from the leaves to other parts of the plant. Notice that the juice which oozes out of the bast-tubes is thicker than water; collect some of it, place it on a glass slide, and test it (1) for starch, (2) for proteids, (3) for sugar. To test for (1) and (2) add a drop of iodine solution; for (3) place some Fehling's solution on the slide with the juice and warm it, or collect enough juice to place in a test-tube and heat with some Fehling's solution.

Exp. 306. Cut off a leaf close to its union with the stem, then make a longitudinal slice through stem and base of leaf-stalk. Scrape off the epidermis, observe that the "node" is solid, and *trace out the bundle connexions in this region, noting the continuity* of the bundles between stem and leaf.

Exp. 307. Split a short piece of Marrow stem and shave off a thin slice from the parenchyma in which the bundles are embedded; *mount in water and examine under the microscope.* Notice that the slice consists of cells which are rather longer than broad; they are many-sided, and are separated by narrow air-spaces at the corners.

Exp. 308. Scrape off the outer soft tissue so as to expose the *hard-tissue cylinder, and from this tear off a narrow and thin strip*; mount in aniline chloride and examine. Notice that this tissue consists of long, narrow cells with tapering ends, that the wall of each cell is thick, and shows here and there small *pits* (pores), that the cells are closely packed together and fit into each other by their pointed ends, and that their walls turn yellow with aniline chloride. The cells of this hard tissue, or sclerenchyma, contain only water, no living substance being present; they are called *fibres*.

Exp. 309. Cut thin transverse and longitudinal sections of Marrow stem. On some place iodine solution; on others, aniline chloride. Notice the epidermis, consisting of a single layer of cells. The ground-tissue lying immediately within the epidermis consists of cells whose walls are thickened, especially at the angles, so that in cross-section the cell-cavity is circular in outline; these cells are seen in a longitudinal section to be rather long, with thick longitudinal walls and thin transverse walls. The thickening substance is cellulose, so that these cells do not turn yellow with aniline chloride. This kind of modified ground-tissue, in which the cells have living protoplasm (usually with chloroplasts embedded in it)

* The Marrow, Cucumber, and some other plants are exceptional in having bast on the inner side of the wood as well as on the outer side. In most stems the bast occurs only on the outer side of the wood.

and cellulose walls thickened heavily at the corners, is called *collenchyma* (fig. 60). It is found in most stems, also in flower-stalks, leaf-stalks, midribs of leaves, etc. It is a strengthening tissue, and is chiefly developed in parts which are still growing; it has the power of growing in length, and it gives elasticity as well as strength to the organ in which it occurs. It is always found just within the epidermis. Within the collenchyma there is a region of thin-walled ground-tissue, separated from the similar tissue in which the bundles are embedded by the cylinder of hard tissue (sclerenchyma).

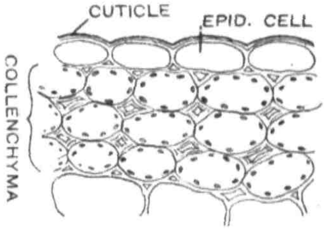

Fig. 60.—Outer Part of Cross-section of Stem of Sunflower showing Epidermis and Collenchyma.

Exp. 310. The most conspicuous part of each bundle is the wood (xylem), which contains the water-conducting vessels. These stand out from the narrow cells lying between them, the largest tubes having on their walls numerous *pits*, or thin places, through which water can pass to the surrounding tissues. These large-pitted vessels lie in the outer part in the wood; each shows plainly in a longitudinal section a series of rings projecting into the vessel and indicating the way in which the vessel was formed—by fusion of cells placed end to end, the end-walls being absorbed. The smaller vessels in the inner part of the wood have spiral or ring-like fibres on the inner side of the wall. These fibres strengthen the vessel, and at the same time allow it to grow in length without the wall being torn. These inner vessels are formed before the large outer ones, while the stem is still growing in length, hence the need for their walls to be thickened only in places, by rings or spiral bands. The wide outer vessels are formed after growth in length has ceased, hence they are thickened all over except in spots which remain thin, forming the "pits."

Exp. 311. In the *bast*, notice the long tubes, best seen in longitudinal sections, each of which is formed from a row of cells placed end to end. In the bast-tubes the cross-walls do not become absorbed completely, as in the wood-tubes; each cross-wall bears a number of pores, so that it resembles a sieve, and hence is called a *sieve-plate*, the bast-tubes being called *sieve-tubes*. The wood-tubes (vessels) contain only water, but the bast-tubes (sieve-tubes) contain dense proteid substance; this is the thick fluid which oozes out when the bast is cut across. The substance filling the sieve-tube passes in strings through the sieve-plates from cell to cell. The sieve-plates can often be seen in surface view in cross-sections of stem; another way to get a surface view of these plates

is to cover a longitudinal section and then press the cover-glass in such a way as to push the sieve-plates over.

Exp. 312. Now examine carefully the part of the bundle lying between the large wood-vessels and the outer bast, using at least a ¼-in. objective. Notice the band of cells extending across the bundle and arranged in radial rows, like a number of ladders side

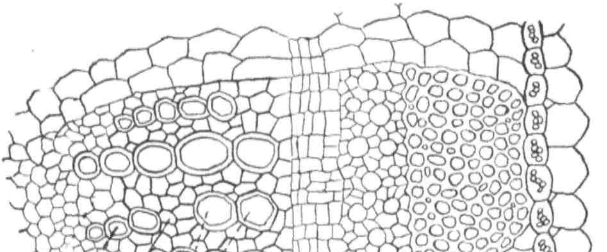

Fig. 61.—Transverse (upper) Longitudinal (lower) Sections of Part of a Sunflower Stem.

by side. This is the *cambium*; its cells have abundant protoplasm, thin walls, and large nuclei (easily seen in iodine-stained sections). The cambium-cells pass gradually into the bast on the outer side and the wood on the inner; they keep on dividing and growing again after each division, and give rise to new bast and new wood, thus adding to the thickness of the bundle (fig. 61).

Exp. 313. In sections through the youngest parts of the Marrow stem, notice that the ground-tissue is complete right across the stem; the cavity found in the older parts is formed by the central region of ground-tissue (pith) becoming torn as the stem grows thicker. Also notice that the wood contains only the narrow spiral and ringed vessels, and that the collenchyma and sclerenchyma are not yet distinguished sharply from the ordinary ground-tissue.

Exp. 314. Cut transverse and longitudinal sections of stem of Sunflower, and compare its structure with that of the Marrow stem (see fig. 61). In the Sunflower the stem is cylindrical, not furrowed; the central ground-tissue does not become torn to form a cavity; the hard tissue (sclerenchyma) is in *separate strands, one immediately* outside the bast of each of the larger bundles. In an old stem, notice that there is a continuous layer of wood, with a complete layer of growing tissue (cambium) on its outer side.

Exp. 315. Cut sections of stem of Dead Nettle and compare with structure of Marrow and Sunflower stems. Notice the central air-cavity; the ring of bundles consisting of a large bundle at each of the four corners of the stem, and smaller bundles between these—*i.e.* facing the flat sides of the stem; the projecting corners containing collenchyma; the shallow air-cavity along each flat side of the stem, a little below the epidermis.

Exp. 316. Cut sections of stem of Maize. Notice that the bundles, although "scattered" through the ground-tissue, are most crowded towards the outside, and that in each bundle the bast side points towards the epidermis and the wood side towards the centre of the stem. In thin sections stained with aniline chloride, notice (1) the epidermis of small thick-walled cells; (2) the narrow band of sclerenchyma below the epidermis; (3) the ordinary ground-tissue (parenchyma) of large thin-walled cells, separated by air-spaces at the corners; (4) the vascular bundles, each with (5) a sheath of sclerenchyma. In a single bundle, notice the four conspicuous vessels arranged like a V, thus: O O
O
O
with narrower vessels lying between; the patch of clear-looking tissue (bast) lying partly between the two larger vessels; and the more or less complete sheath of fibres around the bundle. The larger wood-vessels are pitted; the smaller ones have rings or spiral thickenings. The bast, which stands out distinctly in sections treated with aniline chloride (its walls being of cellulose and therefore not stained), consists of sieve-tubes alternating regularly with narrow cells (companion-cells), but the tubes are narrow and rather difficult to make out (fig. 62). Compare the relative amounts of sclerenchyma and of vascular tissue (wood and bast) in different parts of the section. It is easy to see that the hard-tissue (stained yellow with aniline chloride) is more

strongly developed towards the outside of the stem. In many Monocotyledon stems, the outer bundles are embedded in a layer of hard tissue which forms a complete tube; this is well shown in shrubby plants like Butcher's Broom and Asparagus. Cut sections of the stems of these and of other Monocotyledons, also of the flowering stems of Lily, Hyacinth, etc. In all cases the bundles are more

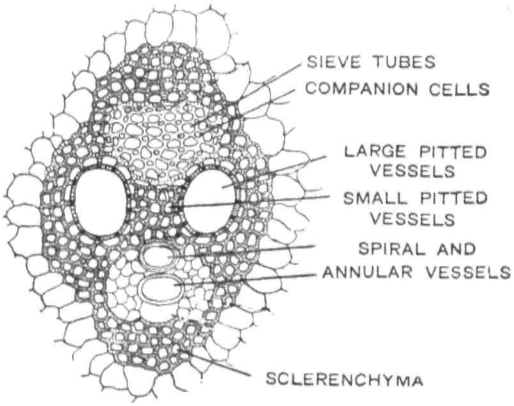

Fig. 62.—Transverse Section of Vascular Bundle of Maize.

crowded towards the outside, and the hard tissue is developed as a layer in the outer part of the ground-tissue. In the erect stems of Monocotyledons, therefore, the "skeleton" or supporting tissue is disposed in the form of a tube, in spite of the "scattered" arrangement of the bundles.

Exp. 317. Cut longitudinal sections of the same stems (or those of other Monocotyledons), and notice the course of the bundles. This can easily be done by cutting thick sections passing through the bases of several leaves and placing them in caustic potash for some time. In these plants, and in most other Monocotyledons, the leaves have a broad insertion, and from them a number of bundles can be traced into them. Their downward course in the stem is not parallel to the surface, but curved. They first run obliquely downwards towards the centre, and then bend outwards again towards the surface (fig. 58). After running through one or two internodes, they join on to bundles passing in from older leaves. At all levels then we obviously have bundles situated at varying depths in the ground-tissue, and it is for this reason that the transverse section shows a scattered arrangement.

200. **Tissues of the Herbaceous Stem.** From the foregoing work on stem-structure, it is evident that the tissues of a herbaceous stem (and the young parts of a woody stem) are of three kinds: (1) epidermis, (2) ground-tissue, (3) vascular tissue (wood and bast).

(1) The epidermis consists of a single layer of cells, with thickened outer walls (cuticle), and bears stomates and often hairs. It agrees closely with the epidermis covering the leaf, and is continuous with it.

(2) The ground-tissue consists mainly of thin-walled cells, those in the centre of the stem often becoming dried up and torn asunder, while those in the regions between and on the outer side of the bundles have various important functions. The cells in the outer region (cortex) usually contain chloroplasts, and are supplied with air which enters by the stomates and traverses the spaces between the cortex-cells; these cells are therefore, like the cells of the ground-tissue (mesophyll) of the leaf, *able to make organic substance* by photosynthesis. The outermost cortical cells often become thick-walled, and form supporting tissue (collenchyma) which differs from ordinary hard tissue in consisting of living cells. The ground-tissue is also modified in places to form sclerenchyma, consisting of *thick-walled* woody fibres, which contain no living substance but only water, and which, *therefore, serve a purely mechanical* function. The sclerenchyma is found outside of the bundles, either forming (1) a complete tube around the whole stem, or (2) a strand on the outer side of each vascular bundle, or (3) a sheath around each bundle (what plants afford examples of these three arrangements?). The sclerenchyma of the stem is continued into the leaf, where it usually forms a supporting band below each chief vein or above it or in both positions. The ground-tissue also serves for the conduction of sugar from the leaf, and for the storage of starch. In Dicotyledons, the new strips of cambium, which are required to form a complete ring of growing tissue around the stem, are formed in the regions of ground-tissue (rays) which lie between the vascular bundles.

(3) The most important structures in the wood- and the bast are the wood-vessels and the sieve-tubes; the former

serve to carry water upwards from the roots, the latter to carry organic substance, especially proteids, to the growing parts of shoot and root. The wood serves also as mechanical (supporting) tissue; it usually contains fibres and ordinary cells (parenchyma) in addition to vessels.

201. **Mechanical Tissue of Herbaceous Stem.** The arrangement of the mechanical or supporting tissue, forming the "skeleton" of the stem, has already been referred to. There is great diversity in the arrangement of the hard-tissue (sclerenchyma), which is, next to the wood of the vascular bundles, the most important supporting tissue of the majority of erect herbaceous stems. Sclerenchyma-fibres, which occur among the vessels in the wood as well as in separate bands or strands outside of the bundles, are *dead* cells (like those which make up the wood-vessels); whereas *collenchyma*-cells are living, and can carry on assimilation, and are also capable of growth, the walls not being hard and woody, as in sclerenchyma. In addition to these three supporting or "skeletal" tissues—wood-vessels, sclerenchyma, collenchyma—the ordinary thin-walled tissue (parenchyma) plays an important part in maintaining the rigidity of stems, as well as of petioles, leaf-blades, and flower-stalks, by the turgidity of its cells. It is easy to show that the parenchyma has a strong tendency to elongate, that this is hindered by the outer tissue, and that the state of strain thus set up tends to keep the stem rigid and erect (Exp. 319). In some plants—*e.g.* Grasses, Sedges, Horse-tails—the epidermis contains flinty substance (silica) which helps in giving rigidity.

Exp. 318. Cut cross-sections of various herbaceous stems, stain with aniline chloride, and examine with lens and microscope, giving special attention to the arrangement of the supporting tissue in the vascular bundles (wood), sclerenchyma, and collenchyma. Of special interest are ridged and winged stems, and the stems of Grasses, Rushes, and Sedges.

Exp. 319. Split a Dandelion stalk longitudinally into four strips, and notice that each strip at once becomes curved, with the epidermis on the concave side. Place some strips in water, others in strong (about 10 per cent.) salt solution, and observe the differences in the curvature caused by the changes in the turgidity of the inner tissue—*i.e.* that nearest the centre of the stalk.

202. **Growth in Thickness**. In almost all Monocotyledons, whether herbaceous (Grasses) or arboreal (Palms), the older regions of the stem are little or no thicker than the younger ones near the growing apex. This is because the stem of a Monocotyledon usually does not undergo any continuous increase in thickness after growth in length has ceased. In dicotyledonous shrubs and trees, however, before the first year is over, a ring of growing tissue or *cambium* appears outside the xylem but inside the phloem, and each year this forms a new cylinder of wood outside the older one, and a new ring of phloem within that previously formed.

203. **Annual Rings of Wood**. In a cross-section of a tree trunk or a thick branch, a series of concentric rings can be seen in the wood. Each of these rings corresponds to one year's growth, although occasionally more than one ring may be added in the course of a year. The number of these *annual* rings approximately indicate the age of the tree or branch (see fig. 63). The wood formed in spring has large vessels which are of great importance for the rapid transport of water, and it is softer than the hard compact wood formed later in the year as the rapidity of growth decreases. During the winter the pressure exerted by the outer tissues upon the cambium often lessens slightly, owing to the cracking of the cork, and as the temperature rises in spring the cambium, being well supplied with food, again begins to grow actively and to form new spring wood. The transition from spring to autumn wood is a gradual one, but there is an abrupt change from the autumn wood of one year to the spring wood of the next. The strong pressure exerted

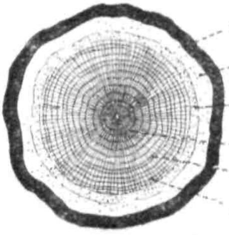

Fig. 63.—Section of Stem with 15 Annual Rings of Wood.
1—5, Duramen; 5—15, Alburnum.

for a few months or even weeks by a tight band placed around the stem may suffice to cause the formation of an "annual" ring, and fluctuations in the amount of food or of water supplied to the cambium may be responsible for the occasional production of several "annual" rings in one year.

204. **Rays.** Running outwardly from the centre of the stem are numerous lines, the medullary rays, which serve partly for the storage of starch and oil, and partly for the horizontal conveyance of food materials and water. They also serve to bind together the successive layers ("rings") of wood, and thus make the wood compact and strong. The rays are vertical plates of parenchyma traversing the wood, cambium, and bast in a radial direction. Their cells are elongated radially. They are not usually more than one to a few cells wide. In height they vary from two to about fifteen cells. They must not be thought of as sheets of tissue running continuously from the base of the stem to the apex.

205. **Heart-Wood and Sap-Wood.** In old trees showing *many* annual rings, the central region of secondary wood becomes distinctly marked off from the peripheral region. This is due to the wood-cells (wood-parenchyma) losing their contents. The result is that the central region contains much less water, and with this there is associated a change in colour. It is darker and harder than the peripheral region. The central region is called the heart-wood; the peripheral region the sap-wood.

It is almost entirely by means of the young sap-wood that water is conveyed upwards from the roots to the leaves, for as the wood grows older it becomes unable to act as a channel for the passage of water. Hence the importance of the addition of new layers of wood is two-fold: first, it provides a connected series of new channels for the ascent of water as the old ones become functionless; and secondly, it increases the strength of the stem as the weight of the upper portion of the tree increases.

206. **Knots.** The knots which occur so commonly in the wood of large tree-trunks are the bases of branches which have become surrounded or covered by new layers of wood as the stem increased in thickness. The hardness of a knot is of course due to the great pressure of the surrounding wood upon it.

207. **Cambium.** The stems of woody dicotyledonous plants increase in thickness by the activity of the *cambium* region. It is obvious that this important zone of growth is most favourably placed in the plant. It is well protected from external influences, and well supplied with necessities of life. On its immediate inner side are the wood-vessels along which the water and inorganic salts pass from roots to foliage; while touching it on its outer side is the soft bast through which manufactured food materials are sent for distribution throughout the plant. Moreover, running through the cambium are the medullary rays, in the cells of which are stored the food reserves of the plant, and from which the cambium can draw supplies when, as in the early spring, no new food is being made by photosynthesis.

208. **Formation of Cork** (fig. 64). It is evident that the internal formation of secondary wood and bast must exert considerable pressure on the outer tissues (cortex and epidermis). The epidermis is stretched and eventually ruptured. To provide for this there is the formation of new tissue from a growing layer developed in this region. This layer is the **cork-cambium.** In the majority of cases (*e.g.* Elder) it arises in the outermost layer of the cortex, immediately below the epidermis. The young cells given off to the outer side of the cork-cambium form a tissue known as **cork**. This tissue, being impermeable to water, cuts off the epidermis from nourishment. The epidermis dies and gradually peels off as the first bark of the tree. The cork is developed to replace the epidermis and carry on its functions.

The Bark may be defined as all dead tissue lying outside an active cork-cambium. We have already indicated what the first bark consists of. The first cork-cambium formed

may persist for a large number of years, *e.g.* the Birch; in the Beech it persists throughout the life of the tree. In such cases there may be a considerable formation of bark owing to the dying off of the older cork-layers. But in most cases this first cork-cambium dies, sooner or later in those plants where it has a superficial origin, early in those where it is deep-seated. It is replaced by a new cork-cambium developed in the deeper tissue. This produces a new cork-layer, and as a result all the outlying tissues (the original cork, etc.) die and are added to the bark. If the succession of secondary cork-cambiums is rapid, it often happens that the cork comes to lie close to the phloem. In some cases, the new cork may even arise in the phloem, *e.g.* Vine and Clematis.

In some trees the bark comes away in sheets, and is spoken of as **ring-bark**. This may be due either to the fact that the first cork-cambium is persistent, *e.g.* the Birch, or to the fact that the successive cork-cambiums appear in the form of regular rings. But in many trees the bark is given off in scales—**scale-bark**—*e.g.* the Plane. This is due to the fact that the secondary cork-cambiums do not arise as regular rings or layers, but in the form of little tangential strips abutting on the previous one.

209. **Lenticels** (fig. 64). In the young green shoot the epidermis, as we have seen, has stomata allowing for the

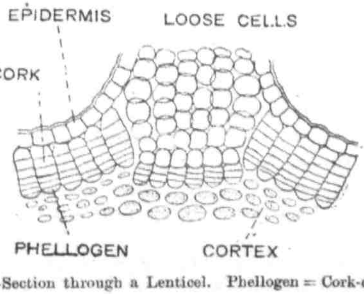

Fig. 64.—Section through a Lenticel. Phellogen = Cork-cambium.

interchange of gases and water-vapour necessary to the life of the plant. When the cork-tissue is developed we usually find certain structures known as **lenticels**. These usually

form small oval scars on the brown surface of the shoot (*e.g.* in the Elder). In Birch the lenticels are long transverse scars, very conspicuous on the white bark. Sections show that at these points the cork-cells are not in close contact, but have separated from each other and form a loose, granular, or powdery mass through which gases and vapours can readily pass. These lenticels are as a rule developed immediately underneath the stomata. Where a thick mass of cork is developed they form long passages or canals, filled with the powdery cork-cells, as, for example, in the ordinary cork of commerce. The lenticels are closed during winter by the formation of ordinary cork-tissue.

Exp. 320. Cut sections of twigs of Elder, Willow, Elm, Oak, or other trees, and notice in the youngest parts the separate bundles arranged in a ring. In the older parts note that the continuous cambium has produced a solid mass of wood on its inner side, while the surface of the stem has become covered by a brown coating of *cork*. Peel off the cork, and notice the green cortex, then a zone of colourless tissue (bast), which is separated from the hard wood by a moist sticky layer (the cambium). Cut sections and stain some with aniline chloride, others with iodine. In the wood, notice the rays which extend from the pith to the bast; these rays consist of cells which in many trees store up food in the winter, usually as starch (test with iodine) or as oils. Notice also that the wood shows a series of concentric lines marking off the successive layers or "rings."

Exp. 321. Next, cut a thin slice out of the thickest part of a branch with a saw, and rub down one of the cut surfaces on fine glass-paper until it is very smooth. Examine it with the aid of a lens, and note the parts as indicated in the preceding paragraph and in fig. 63. In most trees the wood is more or less sharply separated into a light-coloured outer part (sap-wood) and dark-coloured inner part (heart-wood). Examine logs of wood showing the cut surfaces, or the cut stumps of trees in a wood or plantation.

Exp. 322. Strip the cork-layer from twigs of Elder and other plants which show lenticels plainly on the surface, and notice that lenticels are not merely surface-marks, but that they pass right through the cork to the green cortex-tissue. Strip off, layer after layer, the bark of a Birch twig, and notice that the lenticels go through all the layers.

Exp. 323. Dip a twig of Elder, Birch (or other plant which shows lenticels plainly) into boiling water, and notice the air-bubbles which escape from the lenticels. This shows that the green outer tissue of the stem has air-spaces, and that gases can pass through the loose lenticel-tissue.

210. **Continuity of Tissues of Root, Stem, and Leaf.** It is very important to realise that the tissues of the root, stem, and leaves are continuous with each other. In each case the tissues may be divided into (1) Epidermis, (2) Ground-tissue, (3) Vascular tissue.

The epidermis of the leaf and of young stems is a protective layer, preventing excessive transpiration for instance, and where necessary it bears a layer of cuticle or of waxy "bloom," or a covering of hairs, to help in this function; another important function is to allow of the passage of gases into and out of the plant, by means of the stomates. The epidermis of the younger parts of the root serves for absorption, and to increase the absorbing surface root-hairs are developed. In the older parts of the stem and root the epidermis may be replaced by cork, which serves chiefly for protection, but allows the passage of gases through the lenticels which have the same function as stomates.

The ground-tissue, which is continuous throughout the plant, consists primarily of living thin-walled cells, separated by air-spaces which form a continuous system and allow gases to circulate through the plant. In the root, the ground-tissue consists of colourless cells; its chief functions are to convey water from the root-hairs to the wood-vessels, to carry oxygen to the living and growing cells of the root, and to store up food. In the stem, the outer part of the ground-tissue consists of chlorophyll-containing cells which carry on photosynthesis, especially in plants whose leaves are very small or do not remain long on the plant—*e.g.* Horsetails, Gorse, Broom, Asparagus, Bilberry. Part of the ground-tissue of the stem is usually modified to form strengthening tissue (collenchyma, sclerenchyma). The ground-tissue of the leaf is simply an extension of the green outer tissue of the stem, the cells having larger air-spaces between them, and being specially adapted to carry on photosynthesis, while the epidermis contains more stomates.

The vascular tissue (wood and bast) is also continuous throughout the plant. In the root the wood and bast are in separate bundles, but in the transition region between root and stem the root-bundles change in position so that the wood and bast form double or "conjoint" bundles, the

wood coming to occupy the inner side of each stem bundle, twisting round so that the first-formed vessels (spiral and ringed) are nearest the centre in the stem, instead of being external as in the root. The essential parts of the bundles (vessels and sieve-tubes) run continuously from root to leaves, the stem-bundles bending outwards into each leaf so that the wood is on the upper side of each leaf-bundle (vein) and the bast on its lower side. We have therefore three systems of conducting channels running through the plant: (1) the wood-vessels which carry water and dissolved salts; (2) the bast-tubes (sieve-tubes) which carry manufactured organic food, especially nitrogenous substances; (3) the air-passages between the cells of the ground-tissue, through which air circulates, the exchanges of gases between the atmosphere and the living plant-tissues taking place chiefly through the stomates and the lenticels.

211. **Forms of Stem.** Usually the stem is erect and of sufficient strength to support itself, as well as the leaves and flowers which it bears. In other cases the stem is weak, and may either be prostrate or may grow upwards by twining round other plants, or by attaching itself to supports by means of special organs, tendrils, or aerial roots. Climbing stems are usually much elongated, but in other plants the stem may be very short, so that the leaves arise near to the ground,* as in the Daisy and Primrose. Many trees have small shoots or twigs of limited growth, which are known as dwarf shoots. In the case of the apple these bear the flowers, and die after the fruit has fallen. The "needles" of the Pine are borne on dwarf shoots, from each of which a pair of narrow-pointed leaves or needles arise.

Stems may be specially modified to serve as organs for the storage of food, or to act as defensive and protective organs, while in many cases stem-structures may be employed for purposes of vegetative propagation.

As regards the shape of the stem, it may be cylindrical (Grasses and most trees), square (Dead Nettle), triangular

* The unfortunate term "radical" is applied to such leaves, although they do not arise from the root at all.

(Sedges), ribbed (Horsetail and many Umbellifers), or flattened, as in the Sweetpea (fig. 65).

Frequently the adult stem becomes hollow (Grasses, Pinks, and many Buttercups), and usually it is the internodes which are hollow, while at the nodes the stem is solid. The importance of this type of stem is that it gives

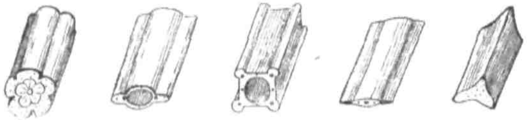

Fig. 65.—Forms of Stem.

a maximum of strength to a minimum of material, and hence it occurs very commonly in rapidly growing herbaceous plants. In these a tall strong stem is formed in the most economical manner possible, and the material saved can be used to produce more numerous flowers and seeds.

212. **Buds.** Before the young stem branches, it is in most cases easy to see that between the base of each leaf and the upper portion of the stem is a little prominence, which consists of a growing apex capable of producing lateral appendages. Each such prominence is a young bud, and may give rise either to a leafy branch or to a flowering one. This region at the base of the leaf, where buds are found, is known as the *axil* of the leaf. All buds are not axillary, however, for the apex of the stem is usually occupied by a *terminal* bud. All of the axillary buds do not develop into branches, for if they did, the foliage would be too closely packed together, and sufficient light and air could not reach all of the branches and leaves. Trees differ very much in the arrangement of their leaves: thus in the Horse-Chestnut and the Beech the outer leaves are comparatively densely packed together, so that buds within the crown of foliage have but little chance of developing into leafy branches, owing to the small amount of light which reaches them. In the Birch or Pine, however, the foliage is more open, and the buds nearer to the stem have perhaps as good

a chance of developing as the more exposed ones at the extremities of the branches.

Whenever any of the branches are pruned away, a number of buds develop which would otherwise have remained dormant, and in this way trees are able to rapidly fill up gaps in their canopy of foliage. So also polled willows soon form a crown of new shoots, and many of these arise either from deep-seated buds, or from *adventitious* ones. The latter are buds which develop out of *their normal order, or without any relation to the leaves.* Adventitious buds may be formed not only upon the stem, but also upon roots or even leaves. Begonias may be artificially propagated by pinning a sliced leaf on damp sand, for buds appear on the wounded edges, strike root, and develop into new plants. Adventitious buds may appear on the roots of the Hawthorn, Apple, Pear, Blackberry, or Dandelion, and may give rise to leafy or even flowering shoots. For example, the roots of the Hawthorn, if chopped into small pieces and covered loosely with damp soil, produce buds and ultimately new plants. In some plants, such as the Walnut and Ash, small deeply situated *accessory* or additional buds may be present beneath each axillary bud, and these usually develop only when the latter is removed.

Buds appear as little prominences on the outer surface of the stem, and are hence said to be *exogenous* in origin, whereas secondary roots arise from within, that is, *endogenously.* Each bud consists of a condensed rudimentary stem in which the internodes are undeveloped, so that the young leaves are closely packed together. Very commonly, especially in winter-time, the bud is covered externally by a number of scaly leaves, the bud-scales, which are often more or less corky, and which help to protect the tender buds within from injury, and more especially from losing too much water. The substance of a bud consists of thin-walled highly protoplasmic cells which are easily killed by drying, *and hence need some special protection against drought.**

* In cold weather the roots are hardly able to absorb any moisture from the soil. Hence a cold, dry east wind shrivels up all the succulent unprotected parts, whereas an equally cold but moist westerly one may hardly affect them.

year, and how many leaves it has borne each time. Observe, and (by noticing the part of the tree the branch occupies) try to account for, the way in which branches differ in their rate of growth in length. Ascertain whether the same marks can be recognised on the branches of other trees. In Horse-Chestnut, Sycamore, Lilac, etc., it is usually easy to distinguish between the buds that will eventually give rise to flowering branches and those which will produce foliage only. The former are usually much more bulky than the latter.

Exp. 327. We have seen that as a bud grows its apex continues to be a "growing-point," thus continuously adding to the length of the branch; and it retains its power of growth even after being severed from the plant, providing it is supplied with the proper food. A bud will often grow if severed from the plant and stood on its base on a piece of flannel kept wet by a nutritive solution, and experiments in this direction should be performed by the student, employing the buds from a variety of plants and trees. Buds grown in this way will often produce new roots at their base, and thus become complete plants.

Exp. 328. In your observations on trees, notice that when a tree is cut down, new buds are formed on the stump; and these, in producing foliage, save the life of the tree, which, of course, could not exist without leaves. Also notice that many trees produce buds which have but little chance of developing because they are shut off from so much air and light by the crowding of the leaves of the plant itself. For instance, the lateral buds of the Horse-Chestnut, Beech, and other trees are so deprived by the abundant foliage at the tips of the branches. Such buds, however, soon develop and restore the natural appearance of the plant if by accident or otherwise the foliage-laden branch-tips are broken off or damaged. Other trees, such as the birch, have such light foliage that lateral buds can develop freely.

The gardener, by pruning his trees, causes buds to develop which would otherwise have remained dormant; and in some cases, by cutting away the tips of the branches which bear only foliage-buds, he encourages the development of fruiting-buds that occupy a position lower on the stems. The process of grafting, so often carried out by the nurserymen, consists in attaching the bud of a plant, together with more or less of the stem, to another of the same species, and in such a manner that the sap of the latter can pass into the former.

Find out all you can about the processes of pruning and grafting, and try experiments in these directions yourself.

Exp. 329. Cut off the young shoot of a Bean seedling a little above the cotyledons, and notice that the buds in the axils of the cotyledons soon grow out to form shoots.

Exp. 330. Cut across the stem of an older seedling, so as to allow only two or three leaves to remain on the stump, and notice that the buds in the axils of these leaves grow out to form branches much

sooner than they would otherwise have done. Notice also that these branches, as in Exp. 329, grow *upwards* almost vertically, instead of the nearly horizontal direction in which branches usually grow.

Exp. 331. Repeat these experiments on other plants, twigs of shrubs or trees, etc. Notice the effects of pruning fruit-trees and clipping hedges.

213. **Forms of Young Leaves in Buds.** To ensure the close packing of the leaves in the bud each one is usually rolled up longitudinally (more rarely rolled up transversely), but sometimes remains flat. Dealing only with longitudinal folding, the leaf may be simply doubled on itself along the midrib (fig. 66, *conduplicate*), or it may be

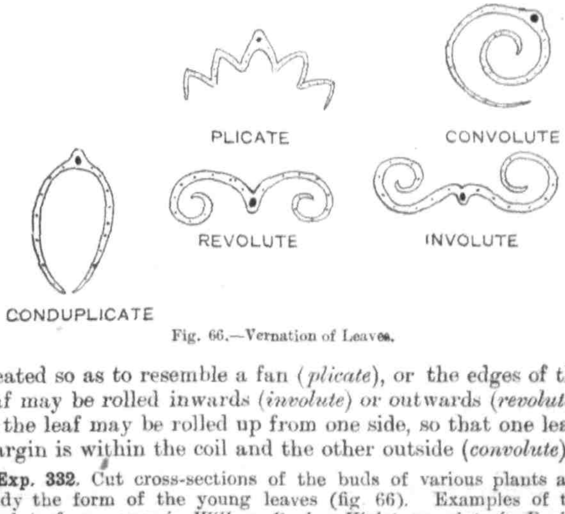

Fig. 66.—Vernation of Leaves.

pleated so as to resemble a fan (*plicate*), or the edges of the leaf may be rolled inwards (*involute*) or outwards (*revolute*), or the leaf may be rolled up from one side, so that one leaf-margin is within the coil and the other outside (*convolute*).

Exp. 332. Cut cross-sections of the buds of various plants and study the form of the young leaves (fig. 66). Examples of the involute form occur in Willow, Poplar, Violet; revolute in Docks; convolute in Plum; plicate in Beech and Sycamore; conduplicate in Rose. Find other examples of each type.

Exp. 333. In the Sycamore, Horse-chestnut, etc., make sections through the parts belonging to successive years, stain with aniline chloride, and observe the rings in the wood. The section through the terminal part (last season's growth) shows a uniform ring (hollow cylinder) of wood round the pith; below the first series of crowded

scars (position of last winter's terminal bud) the wood shows in section two distinct layers; and so on, the annual rings seen on cross-section agreeing with the age of the part as determined by inspection of the twig.

Exp. 334. For each plant whose buds you examine, try to find out the nature of the bud-scales, which may be (1) leaf bases without stalk or blade (Sycamore, Horse-chestnut); or (2) rudimentary leaf-blades (Lilac, Privet); or (3) stipules of leaves which develop a blade (Alder, Elm); or (4) stipules of leaves (scale-leaves) which develop no blades (Oak, Beech).

214. **Mode of Branching.** Each bud encloses a growing apex protected and hidden from view by the surrounding young leaves. It has already been mentioned that the axillary buds give rise to lateral branches, and under normal circumstances all the branches arise in this manner in flowering plants, although it sometimes happens that the branches become stronger, stouter, and longer than the primary axis from which they arise. This type of branching, in which the energy of growth is continually transferred to the lateral branches, is said to be *cymose* (fig. 67 C), whereas the more usual mode of branching is *racemose*.

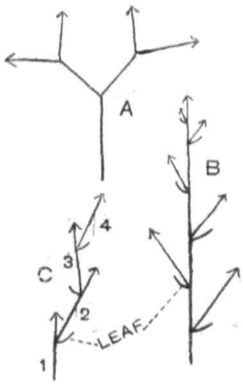

Fig. 67.—Forms of Branching. A, Dichotomous; B, Racemose; C, Cymose.

The various types of indefinite or racemose branching will be discussed in connection with the inflorescence, but a few words may be said with regard to the different forms of definite or cymose branching. In this the main axis soon ceases to grow, and one or more lateral buds placed a little distance behind the apex continue the growth of the shoot by giving rise to secondary branches. If only one daughter axis is formed at each branching, the latter is said to be uniparous (fig. 68 A and C), if two, biparous (fig. 68 E), if more than two, multiparous. In the case of uniparous cymes, the successive branches may be

developed either right and left alternately (fig. 68 A), or else all on the same side (fig. 68 C). The branching would in the first case follow a zigzag course, and in the second a spiral one, if the branches retained the position which they should theoretically occupy. As a matter of fact, however, they develop in such a manner that their basal portions form successive increments to the main axis, and hence the whole system of branching is straightened

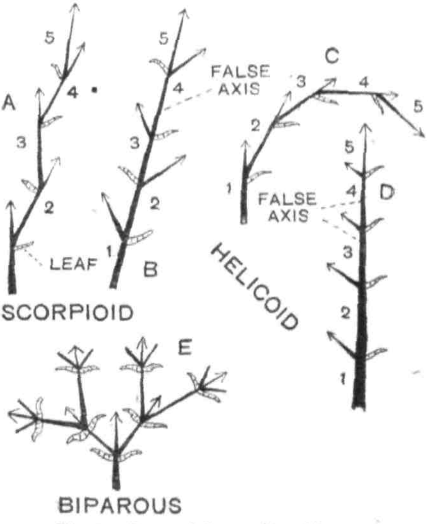

Fig. 68.—Forms of Cymose Branching.
A—D, Uniparous.

out so as to form a continuous central axis, from which lateral branches arise in an apparently racemose manner (fig. 68 B, D). The scorpioid form resembles a simple raceme (cf. fig. 67 B), the helicoid, a one-sided raceme. When a parent axis is formed in this manner, it is known as a *sympodium* or false axis. An important point to remember is that the position of the subtending leaves will differ in the sympodium from that in the true raceme,

for they will be on the side of the stem opposite to the apparent lateral branches.

Among British trees, the Birch, Elm, Beech, Hazel, and Lilac have sympodial branches. They are produced owing to the death of the terminal bud, when one of the nearest axillary buds grows out in the same direction as the parent branch, and continues its onward growth.

There is another type of branching, which, however, occurs only among flowerless plants such as Seaweeds, Liverworts, Club-mosses, etc. This consists in the direct division of the apex of the stem into two branches of equal size, and hence it is termed *dichotomy* (fig. 67 A). Very commonly one of the branches grows more actively than the other, as occurs, for example, in the common brown seaweed known as Bladder-wrack. In some flowering plants what is known as false dichotomy occurs. It is really a form of the biparous cyme, in which the growing-point of the parent axis does not develop, so that the lateral branches appear to arise by the direct division of the parent axis into two. This type of branching is shown by the Mistletoe, in which the terminal bud produces a flower, and by the Lilac.

To obtain a practical acquaintance with this subject, a series of different stems should be examined, preferably those of herbaceous plants, for in shrubs and trees usually only a portion of the buds develop into branches, and hence the actual arrangement of the latter may differ considerably from what it should be theoretically. The racemose type of branching is by far the commoner in the vegetative parts of stems, but cymose branching is frequently met with in trees as a secondary specialisation: thus the branches of the Elm and Lime afford instances of uniparous cymes. Among herbaceous plants, Campions and the Pink family in general afford very good examples of biparous cymes.

215. **Trees, Shrubs, and Herbs.** Stems differ very much as regards their toughness and rigidity, as well as the age and size which they may attain. Herbaceous stems rarely outlast their first season, although in such garden plants

as the Sunflower, Hollyhock, and Wallflower they may be of considerable size and comparatively firm and rigid. With the exception of some forest trees,* plants in this climate do not attain any great height, although in climbing plants like the Convolvulus, White Bryony, or Hop the stem may attain a considerable length. A few herbs, however, of which the wild Angelica and the Cow-parsnip may be taken as examples, reach a height of 4 ft. or more in a single season, and such garden plants as the Giant Cow-parsnip and the Sunflower may become 12 to 15 ft. high. Herbs may either be annual, or they may possess perennial underground stems which send up new shoots season after season.

Trees and shrubs have woody stems, and are able to exist for considerable periods of time, which in the case of certain trees (Oak, Beech, Yew, etc.) may extend to hundreds of years. A tree usually possesses a stout, main trunk from which smaller and more slender lateral branches arise. Frequently, however, the main stem is short, and is exceeded in length by the secondary branches. A shrub, on the other hand, is simply a miniature tree, its primary stem being usually short, and soon breaking up into numerous more or less erect lateral branches.

216. **Aerial Stems.** These are usually erect, as in trees, and in such herbaceous plants as the Sunflower and Hollyhock, but in other cases the stem is weak and reclining, or ascends by means of external supports. In some plants the aerial portion of the stem is very short, so that the leaves seem to spring from the top of the root, while arising from the centre of the tuft of leaves is the upright flowering axis. The eminently misleading term "radical" is often applied to such leaves, and the condensed portion of the stem, together with the upper part of the root, is known popularly as the "root-stock." Very commonly this is perennial, and forms flowers and new tufts of leaves year after year, as in the Plantain, Daisy, and Dandelion.

Many plants produce highly specialised lateral branches, which serve mainly for purposes of vegetative reproduction.

* See Ch. IX.

for they will be on the side of the stem opposite to the apparent lateral branches.

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Thus the runner of the Strawberry is a lateral branch which grows horizontally on the surface of the soil, and which may attain a length of 2 or more feet. It arises in the axil of one of the foliage leaves, and at intervals of a few inches produces small scale leaves, each of which bears a bud in its axil. Adventitious roots develop from the bases of these buds, which then produce foliage leaves and ultimately a new flowering axis; the latter usually forms after the connecting portions of the runner have withered away. In this way a single runner may under favourable conditions produce as many as ten or twelve new plants. In the House-leek, on the other hand, the runners or "offsets" are short, and carry out large rooting buds from the parent plant. The "suckers" of the Rose, Raspberry, and Mint are lateral branches arising below the level of the soil, which grow upwards to form sub-aerial stems bearing leaves and flowers. The subterranean portions of such stems resemble roots, and are white or pinkish in colour. Their true character can, however, be told by their axillary exogenous development, and by the occurrence of scale-leaves upon them. In some cases, however (Roses and Poplars), the suckers arise endogenously from roots, but the growing apex soon becomes like that of a stem. Probably the very young root becomes transformed into a stem-structure.

217. **Climbing Stems.** Many plants with weak stems have special means of growing upwards towards the light, and of placing themselves in the most favourable positions for growth and development, for flowering and fruiting. Climbing stems have relatively long internodes, and would be prostrate in the absence of any external support. They may climb (1) by means of special aerial roots, (2) by twining around supports, (3) by the aid of special irritable organs, which are usually known as **tendrils.** These respond to contact with a support either by twining around it or by attaching themselves to it in some other manner. A few plants, such as the Blackberry (*Rubus fruticosus*) and the Goose Grass (*Galium Aparine*), are able to climb by means of the prickles which are scattered irregularly

over the surface of the stems and branches, especially when the prickles are curved with a downwardly directed point. Such plants may be termed **scramblers**, and they are extremely suggestive as indicating the possible first effort in the direction of obtaining secondary support.

The Ivy forms a good example of a plant which climbs by means of aerial adventitious roots which develop at the nodes and along the shaded surface of the stem. These adhere to the roughnesses or crevices in walls or tree-trunks.

In the case of **twining plants**, the stem coils around neighbouring objects, which must not be above a certain thickness if complete coils are to be formed. Most twiners twine in the opposite direction to the sun (fig. 69 I.),

Fig. 69.—I., Convolvulus Stem twining against the Sun; II., Hop twining in same direction as the Sun.

but a few, such as the Hop and Honeysuckle, follow it (fig. 69 II.). In most cases twining only occurs around supports which are more or less erect, and are not above a certain thickness, for the stems of twining plants have a strong tendency to ascend directly upwards by the shortest possible path. The Convolvulus (*Calystegia sepium*), however, will twine around an almost horizontal piece of string,

whereas the Hop will not twine around supports more than 45° from the perpendicular, or thicker than 4 in.

Tendrils. Very many plants climb by means of special irritable attaching organs, or **tendrils**. These are elongated filamentous outgrowths, which may branch, and which possess the peculiar property of being able to coil around any thin supports they may touch. As they grow they sweep slowly round through the air (*nutation*, or nodding movement) until arrested by an object within reach. It is the stimulus of contact which induces the coiling, and the very sensitive tendrils of the Passion-flower (*Passiflora*) may be caused to coil by hanging a loose loop of thread near to their extremities, where the most irritable region is situated. Tendrils can embrace suitable objects, however these may be placed with regard to the vertical, and they may even clasp such objects as loose straws, which are incapable of yielding them any support. Tendrils may be either stem-structures or leaf-structures. In the former case they arise in the axils of foliar organs, and very commonly bear minute scale-like leaves. Examples are afforded by the Passion-flower, the White Bryony, and the Vegetable Marrow. In some cases tendrils arise by cymose branching from what is really a sympodial axis, and hence each tendril is found on the side of the stem opposite to the base of a leaf. The tendrils of the Vine have this character, and they may be either modified foliage branches or modified flowering ones. In the latter case the tendrils aid especially in supporting the bunches of grapes, and in Gourds and Marrows the weight of fruit thus supported may amount to a hundredweight or more.

Leaf-tendrils may be recognised by their mode of origin. Thus the terminal leaflet of the compound leaf of the Pea is modified into a branched or unbranched tendril, and in some cases several of the leaflets undergo a similar metamorphosis. The leaf of the Fumitory is divided into fine segments, and any one of these may act as a tendril and coil around a support.

When a tendril has become attached, it always becomes stronger and more elastic, and in the case of shrubby climbing plants it undergoes a secondary increase in thick-

ness. This latter occurs because the tendril of a shrub may act as a supporting organ for several years, whereas in herbaceous plants it functions for a single season only. The leaf-stalks of *Clematis* and of the woody Night-shade (fig. 70) act like tendrils, for they coil around slender supports, and become thicker and stronger after they have been attached for some time. It is interesting to notice that to a certain extent the strength of the adult attached tendril becomes ultimately proportional to the weight which it has to bear, so that if a number of the young attached tendrils are removed, the remaining ones become stronger, provided that they are still capable of growth.

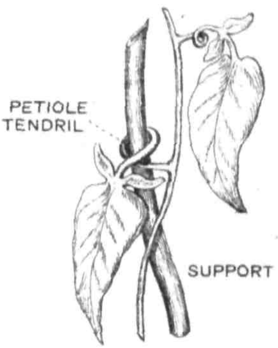

Fig. 70.—Leaf Stalk of Solanum twining round a Support.

The long filamentous tendrils characteristic of herbaceous plants simply become harder and more rigid when attached, while the free portion between the plant and the support is thrown into several spirals in opposite directions. The effect of this is to form an elastic spring, which enables the attached plant to yield to the wind, and acts as a buffer against violent shock which might injure the plant or tear away the tendril from its support. Old unattached tendrils ultimately coil up, but the coiling usually takes place all in one direction, and the tendril soon withers and falls off.

The tendrils of the Virginian Creeper (*Ampelopsis*) attach themselves by means of disc-like outgrowths or "suckers," which develop at their extremities, and, owing to this peculiarity, the plant can climb up any slightly roughened surface.

Exp. 335. Grow a Scarlet Runner seedling in a pot, tying the lower part of the stem to a stick, and when about 6 in. of the stem project beyond the stick bend this free part over so that it hangs horizontally. Place a sheet of paper below the pot and draw lines

radiating from the centre of the pot, then find the direction in which the free part of the shoot points, and notice the rate at which it swings round. A healthy plant will make a complete circle in about two hours. Provide a similar seedling with a long stick, and notice that the direction of climbing is the same as that of the swinging movement (*nutation*) of the free end—that is, from left to right upwards (against the hands of a clock). Dig up small plants (or grow seedlings) of Hop, Honeysuckle, and Convolvulus, and make similar observations, noting the direction of movement in each case.

Exp. 336. Using the same plants, find out the effect of using sticks of different thicknesses, and of placing these sticks (or stretched strings) at differing angles, from horizontal to vertical.

Exp. 337. Notice that young tendrils of Vetches, Sweet Pea, White Bryony, etc., which have not yet become attached, show a slight hook at the free end. Rub the concave side of the hook with a pencil, and notice that this part soon begins to curve (White Bryony and Passion-flower show this very quickly), and in a few minutes forms a complete coil. Rub the outer (convex) side of the hooked end of another young tendril, and notice that no bending occurs; the convex side is not sensitive to contact.

218. **Underground Shoots,** being less exposed than those above ground, are commonly used for the storage of food, and they may serve either for the maintenance of the life of the individual when the parts above ground are killed by winter frosts, or for the production of new individuals by vegetative propagation. They may be distinguished from roots by the fact that they bear leaves or buds, and by their origin from buds borne in the axils of leaves or leaf-scales.

The four chief types of underground stems are—rhizomes, tubers, corms, and bulbs.

The **Rhizome** is a stout or slender underground stem of variable length, which usually grows horizontally a short distance beneath the surface of the soil. Stout, partially upright rhizomic stems are sometimes termed "root-stocks," but they can be distinguished from roots by the fact that they bear leaves and buds, as well as by their internal structure. Usually only small brown membranous scale-leaves arise directly from the rhizome, the green foliage leaves being borne upon erect aerial shoots. Numerous adventitious roots are present, which grow out mainly from the under-surface of the rhizome, and usually near to the

bases of the scale leaves—that is, from the nodes. Rhizomes often branch to a slight extent, and each branch when separated, either artificially or by the decay of the older parts, is capable of forming a new plant. It is in this way that the vegetative propagation of Irises is effected.

Many rhizomes are sympodial stems, the apex growing up each year in the form of a sub-aerial shoot, while a lateral bud developed in the axil of a scale leaf continues the horizontal growth of the rhizome. The latter is hence composed of the horizontal basal portions of a series of

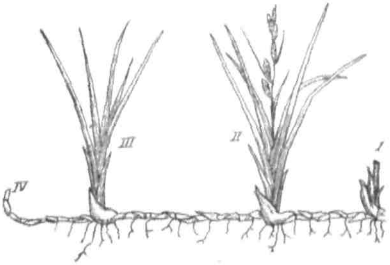

Fig. 71.—Rhizome of Sedge (Carex) in Summer.
Flowering shoots of (I) last year, (II) this year, (III) next year, (IV) year next but one.

lateral shoots, which persist after the erect aerial parts have decayed away. Hence a rhizome of this character slowly travels to fresh and unexhausted regions of soil. Most ordinary rhizomes slant obliquely upwards, and hence grow towards the surface. The new portions are, however, dragged down to the same depth by the contraction of the roots as they grow old. Examples of sympodial rhizomes are afforded by creeping Grasses, Sedges (fig. 71), and Reeds, by the Wood-anemone, and by Solomon's Seal (fig. 72). The scars left behind by the scale leaves and by the sub-aerial shoots can usually be detected on the surface of the older portions of the rhizome, and the scars left by the shoots indicate the increments of growth formed during successive years.

The slender rhizome of the Wood-sorrel is a stem which grows horizontally, usually a little distance below the surface of the soil, but sometimes actually upon it. The rhizome bears fleshy scale-leaves, in whose axils flowering shoots arise, each bearing a single terminal flower and a

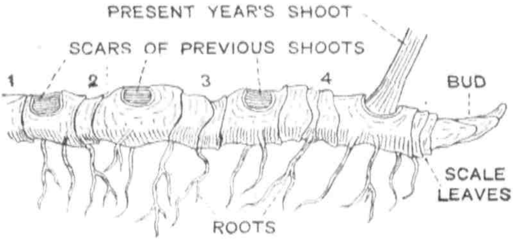

Fig. 72.—Rhizome of Solomon's Seal.
The numbers represent increments of successive years.

pair of minute leaves half-way up the branch axis. The trifoliate foliage leaves are also directly attached to the rhizome, which is a continuous main axis, and is hence closely related to such a creeping stem as that of the Ground Ivy, which grows horizontally on the surface of the ground and gives off roots at the same nodes from which the leaves arise.

219. The **stem-tuber** is a swollen subterranean shoot (fig. 73) gorged with food material, and serving for purposes of vegetative propagation. Examples are afforded by the Potato, the Jerusalem Artichoke, and the Pig-nut. The tubers of the potato are borne on slender subterranean shoots which bear scale leaves, and they develop either at the ends of these shoots or from short branches arising in the axils of the scale-leaves (fig. 73). They are at first very small, but grow rapidly, and become loaded with starch and other food-materials. The Potato is readily recognised as a stem structure not only by its mode of origin, but also by the presence of buds or "eyes" upon it. These develop into erect shoots, which are nourished by

the food-materials of the tuber, and which may attain a considerable size when a large Potato sprouts in darkness. Each bud if attached to a portion of the tuber can develop into a new plant. Hence farmers usually slice their larger "seed" potatoes into several pieces before planting, each piece consisting of a portion of the tuber and one or more "eyes."

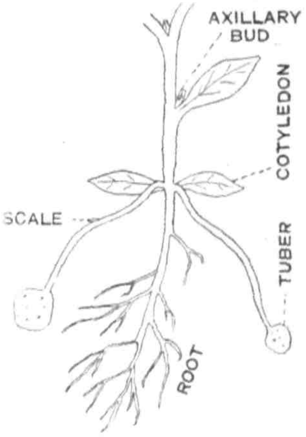

Fig. 73.—Seedling of Potato with Developing Tubers.

220. **Corm.** The corm is a bud which develops roots, and whose basal stem-portion becomes swollen and filled with food-materials after flowering has taken place. The corms of two or three years adhere together so as to produce what may be regarded as a condensed form of rhizome bearing axillary buds either laterally (*Colchicum*), as in a creeping rhizome, or on the upper surface (*Crocus*), as in the upright type to which the name of "root-stock" is often applied. The swollen portion of the corm is packed with food-materials, and bears a few brown scale leaves. The buds develop in spring into erect flowering shoots at the expense of the stored food-materials, while adventitious roots arise from the base of the bud and also from that of the condensed stem. Later in the year, when flowering is over, the new supplies of food-material, together with any remaining in the old corm, are stored up in the basal portion of the flowering shoot, which swells to form the new corm. The old corm shrivels up, and a bud arising from the new one forms the flowering shoot of the next year when winter is over, the life history being repeated in this manner from year to year.

Additional buds may sometimes develop in the axils of

the outer leaves, each producing a new corm. These subsequently separate and form new plants. The same process occurs in bulbs, especially when they are sliced across near the base.

221. **Bulb**. The bulb only differs from the corm in the relatively smaller size of the stem, and in its investment by thick fleshy leaves, which contain large stores of reserve food. As in the corm, adventitious roots arise from the base of the stem, which usually assumes a discoid shape. In scaly bulbs (Lilies, Tulips, etc.) the fleshy scales, of which the main bulk of the bulb is composed, simply overlap at their margins, whereas in tunicated bulbs (Onion, Hyacinth) the outer leaves are large and completely ensheath the inner portions of the bulb. The coloured membranous covering on the outside of such bulbs is formed by the shrivelled remains of the leaves of a previous season.

The bulb of the Hyacinth is composed of the enlarged persistent bases of foliage leaves, but it also includes a certain number of scale leaves. A bud arises in the axil of the innermost leaf, and next spring this will develop into a flowering axis, surrounded by a number of foliage leaves, and outside of these a few scale-leaves. The outermost scales of the previous year shrivel, the inner ones persist, together with the bases of the foliage leaves, and the enlarged axillary bud now forms the central portion of the new bulb. This may continue for several years, but ultimately two or more buds develop in the axils of the upper leaves. As they grow, they rupture the parent bulb, and are set free, after having absorbed a large amount of nourishment from it. Buds, composed of scale-leaves enclosing foliage leaves, may also develop in the axils of the outer scale-leaves.

The resting bulb of the Snowdrop is composed of the persistent fleshy bases of two long, narrow, foliage leaves, and of an outer sheathing leaf. The base of the flower-stalk may also be present. The whole is surrounded by the shrivelled bases of the leaves of the previous season, and in the centre of the bulb a bud develops in the axil of the uppermost foliage leaf, and forms the flowering axis in

spring. A bud may also develop in the axil of the sheathing leaf, and may ultimately separate as a new bulb.

Bulbs, tubers, and *corms* afford a means of perennation and also of vegetative propagation. They occur most commonly in the group of Monocotyledons, but are found among Dicotyledons as well, for several species of *Oxalis* have true bulbs. They are characteristic of plants which are exposed to the dangers of drought or of cold. In many cases the possession of such subterranean stems enables plants to compete successfully in the struggle for existence with ones which are better equipped in other respects.

Exp. 338. Runners. Examine a strawberry plant from which runners have been thrown off, and note that (1) the "plant" represents the swollen leaf-bearing end of a slender horizontal stem (runner) which bears only small scale-leaves; (2) the leafy tip of the runner curves upwards, and that roots arise from the lower side of the curve; (3) young runners arise from buds in the axils of the lowest foliage-leaves, each runner repeating the structure of the older "plant." Note the three kinds of leaves in the Strawberry: (1) the scale-leaves on the runners, (2) the long-stalked foliage-leaves arising from the base of each "plant," (3) the leaves carried on the flowering shoots.

Exp. 339. Rhizomes. *Iris.* Examine the rhizome of Iris. Note (1) the stout central axis carrying (2) a terminal shoot, (3) several lateral shoots, (4) dormant lateral buds, and (5) a series of rings on the central axis formed by the circular scars left by the decayed leaves of previous years. Observe that the roots spring from the rhizome along its under side, and also from the bases of the lateral shoots. Pull off one of the lateral shoots, and note that (1) the leaves are flat and elongated, arranged in two opposite rows, and so set that they all lie in the same plane; (2) towards the lower extremity of each leaf the blade gradually passes into a tightly fitting sheath, that is inserted upon the axis of the young rhizome by a broad base that completely encircles it. Carefully remove the leaves one by one, noting their arrangement on the stem, and notice on the side of the axis of each young rhizome, near its base, a bud or buds, each of which has the power to grow into a shoot similar to the one you are examining. Scrape the tissue of the axis of the rhizome, and examine the scrapings for starch.

Solomon's Seal. Study the rhizome of this plant; it is formed of a stout, straight axis, carrying (1) numerous roots springing from points all over its surface; (2) a strong terminal and a few weaker lateral buds; (3) scars on its upper surface indicating the positions of flower stems of previous years. Notice that the terminal bud bears flowers as well as leaves, and that the main axis grows in length by the growth of successive lateral buds.

Exp. 340. Tubers. Examine the tuber of Jerusalem Artichoke (*Helianthus tuberosus*, allied to Sunflower). It is the much-thickened end of a short underground branch. Notice the buds in the axils of the short, broad, scaly leaves. Pull back one of these leaves, and examine the bud carefully; the outer leaves of the bud are crowded together, forming a smooth, continuous surface. Compare with this tuber that of a Potato, distinguishing between the base and apex of the modified underground branch. Observe that the buds are relatively small in the Potato, and that they are hidden in pits or "eyes." Make a vertical section through one of the "eyes," and look for the bud. Make sections or scrapings of the internal tissue of the tuber and examine the starch-grains, observing their stratification (fig. 74); stain with iodine. Compare the starch grains of Potato with those of the other plants you have studied, and note how they differ in size and shape. Does the tuber of Jerusalem Artichoke also contain starch? Grow the tubers in damp soil or sawdust, some in the light, others in darkness.

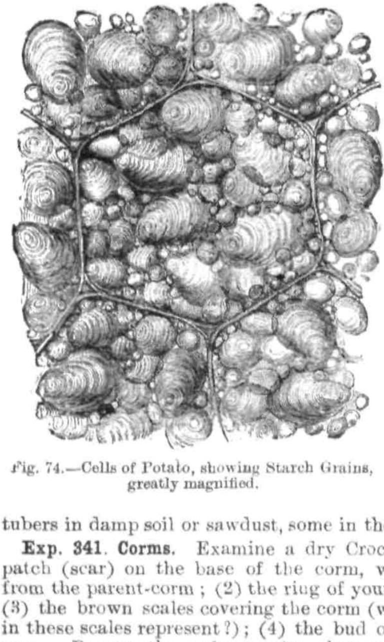

Fig. 74.—Cells of Potato, showing Starch Grains, greatly magnified.

Exp. 341. Corms. Examine a dry Crocus corm. Notice (1) the patch (scar) on the base of the corm, where it became detached from the parent-corm; (2) the ring of young roots around this scar; (3) the brown scales covering the corm (what do the fibrous strings in these scales represent?); (4) the bud or buds at the top of the corm. Remove the scales, noting that each leaves a scar running round the white solid part (swollen stem) of the corm, and that above each scar there is a bud on the corm, the lower buds being usually very small, while those at the top of the corm are larger. Carefully dissect one of the large buds, noting (1) the white sheathing scale-leaves; (2) within these, the yellowish foliage-leaves, each long and narrow, with a broad sheathing base, two leaves sometimes arising from one basal sheath (why are these young leaves yellow, instead of green, while enclosed in the bud?); (3) the flower-bud (sometimes several), with one or more flowers, enclosed in

a sheath (bract); (4) the parts of the flower, all present though small (inferior ovary, long perianth-tube, six perianth-lobes, three stamens, style with three fan-like stigmas); (5) the stem part of the bud, slightly swollen, which will later form a new corm. Make a vertical section through the corm, passing through a large bud; sketch the parts seen, touch the cut surface with iodine, also scrape it and examine the scrapings (mounted in water and in iodine solution) with the microscope. Plant dry corms in damp soil or sawdust, and watch the growth of the roots and the buds and the *formation of a new corm from each bud; make notes and sketches* of your observations. Notice the ring of roots produced at the base of each corm, and the growth of the bud or buds at the top. Cut sections through the bases of the latter, to show the new corms beginning to develop.

Exp. 342. Bulbs. Make a similar examination of the bulbs of Tulip, Daffodil, White Lily, Hyacinth, Onion; compare them with each other and with the Crocus-corm, the rhizome, and the tuber. Remove the scales, and notice the small discoid stem to which they are attached, and the buds in the axils of some of the scales. Ascertain which of the scales are entire leaves and which the basal parts of foliage-leaves whose upper parts have withered. Cut a bulb of each kind in half longitudinally, and sketch cut surface. Test cut surfaces with iodine; the Onion contains sugar, not starch, in the swollen scales. Plant bulbs in damp sawdust, and notice the roots, the growth of the buds, and the formation of new bulbs. Make full notes and sketches in every case.

222. **Spines, Prickles, Hairs.** In many cases stems become metamorphosed into spines, which terminate in a hard, sharp point instead of in a bud or soft growing-point. Many of the branches of the Sloe, and also of the Hawthorn, become modified into special protective organs of this nature. That they are really branches which have ceased to grow and whose apices have become hard and sharp-pointed is indicated by the fact that they arise in the axils of leaves, and that they may bear lateral buds or even small foliage leaves. Such spines possess a central cylinder of vascular tissue, which is continuous with that of the stem, and hence when they are torn off they leave a deep wound in the latter.

Spines may also be developed either from entire leaves or from the edge of the lamina. The latter is the case with regard to the spines on the margins of the leaves of the Holly and Spear Thistle, for these are clearly simply hard and sharp-pointed outgrowths of the lamina or blade

of the leaf. As in the case of stem-spines, they serve for purposes of protection. The branched spines of the Barberry and the unbranched ones of the Salt-wort are modified leaves, for in their axils buds are present which may develop into leafy branches or flowering ones. Moreover, the same Barberry plant (fig. 75) often exhibits intermediate forms between leaves and spines. The foliage leaves of the garden Acacia (*Robinia*) have a pair of spines which arise at the base of the leaf-stalk, and these are really modified *stipules*. The thorns of the Gorse (*Ulex europaeus*) are either modified branches or modified leaves, for some of them bear buds in their axils, and are distinctly narrow-pointed leaves, whereas others form the hard sharp-pointed ends of branches. The young seedling bears normal foliage leaves, but these are replaced by spines as the plant grows older. This is a sign that the plant originally had normal foliage leaves, and that it acquired its present peculiarity for some special reason, probably originally as a protection against drought and excessive illumination, although now it serves to ward off herbivorous animals.

Fig. 75.—Branch of Barberry, showing transition of Foliage Leaves into Spines.

In addition to the above, prickles and hairs may be scattered irregularly over the surfaces of plants, the former mainly on the stem, but the latter on the stem, leaves, and roots. Hairs may assume a variety of shapes, but they are always derived from the layer of cells forming the epidermis, or first outer skin, of plants, and hence they fall off when cork is formed. The Nettle has three kinds of hairs (fig. 76), the largest of which are the stinging hairs. The point of the stinging hair is formed by a sharp, thin, brittle scale of silica, which breaks off in the skin, leaving a tiny wound into which the acid juice contained in the hair is squirted by the contraction of the swollen

base. If a nettle leaf is firmly grasped between the fingers, the hairs are usually bent or crushed before they can sting, and no stinging is possible if the plant is drooping from want of water.

Hairs are frequently glandular (fig. 76 B) and often sticky. In the latter case they are of use as a protection against obnoxious creeping insects, which are frequently caught and retained by the glutinous secretion. The leaves of a few plants, such as the Butterwort (*Pinguicula*) and the Sundew (*Drosera*), have actually acquired the power of partially digesting insects which are so unwary as to be captured in this manner.

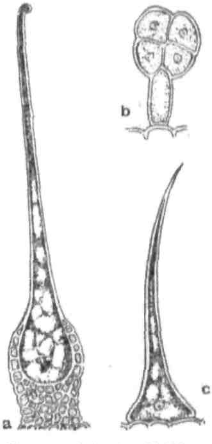

Fig. 76.—Stinging Nettle.

a, Stinging hair; b, Multicellular glandular hair; c, Ordinary unicellular pointed hair. (Highly magnified.)

Prickles such as those of the Rose are usually classified as "emergences." This term is merely a conventional expression for all irregularly situated outgrowths from stems or leaves of constant occurrence and definite shape, but which are neither hairs, roots, branches, leaves, leaflets, nor stipules, and which neither bear buds in their axils nor arise in the axils of leaves. Emergences arising from the stem usually contain no vascular tissue, and hence, when removed, they leave only a superficial wound (as in Roses and Brambles). Each of the stalked glands on the leaf of Sundew, which are also regarded as emergences, contains, however, a strand of vascular tissue arising from one of the veins of the leaf.

Exp. 343. Show by sections that the spines of the Hawthorn or of Blackthorn are modified branches, being outgrowths of the vascular tissue, that the prickles of the Rose and Bramble are outgrowths of the epidermis and cortex, and *do not contain vascular tissue*, and that the hairs on various herbaceous stems are outgrowths of the epidermis alone.

4. Explain the structure, as seen in transverse section, of a twig of any Dicotyledonous tree.

5. State generally what is the composition of a vascular bundle. Describe the longitudinal course of the vascular bundles in the stem of any Dicotyledon.

6. What is the cambium? Explain where you would find it in the stem of a tree, and what is its importance.

7. What is meant by a "vessel"? What are the differences between the vessels of the wood and those of the bast?

8. What is a "growing-point"? What is the difference between the growing-points of stems and those of roots?

9. Describe the way in which the stem of a Dicotyledonous tree grows in thickness, and explain how it is that its wood shows annual rings.

10. The stem of an Oak tree continues to grow in thickness so long as the tree lives, whereas the stem of a palm-tree does not grow any thicker when once formed. Explain the cause of this difference.

11. Along what tissue does the sap ascend in a stem in its passage from root to leaf? How would you endeavour to prove by experiment the truth of your statement? What other movement of liquid substance takes place in plants besides the ascent of the sap, and what is the path of this current?

12. Explain as far as you can the way in which water is absorbed from the soil by the roots, and the transpiration current maintained, in the case of trees.

13. What is meant by sclerenchyma? Give some account of its mode of occurrence in stems, and show how it is of use to the plant.

14. Describe the process of secondary thickening as seen in the root of a Dicotyledonous tree. What advantages does this secondary thickening confer on the tree?

15. Describe in the case of any seedling you may select how the structure characteristic of the root changes into that met with in the young stem. What do you think is the use of the change to the plant?

16. What method, other than watering, would you use to recover a plant, growing in the open, which had become flaccid from loss of water? Give reasons for the method adopted.

17. What are adventitious shoots? Under what circumstances are they most readily produced? Mention three examples.

18. Describe accurately an experiment which you have seen in which the rate of growth of roots or shoots was measured. Which part of the root grows most rapidly in length, and which part absorbs most water? What advantages do plants gain by the increase of their shoots and roots in length and thickness?

19. Why does a succulent flower-stalk or petiole lose most of its rigidity when cut and in want of water? Could you produce this condition artificially without exposure to the air? How would you

attempt to restore the rigidity of a stalk thus artificially wilted? Give reasons for your answers.

20. Describe and explain the changes that may be observed when a turgescent shoot is bisected longitudinally, and when the halves are placed successively in water and in strong salt solution.

21. The split stalks of cut flowers have been found to become limp in salt-solutions containing 32·5 grm. of salt per litre; but to become turgid in solutions containing 3·25 grm. per litre. Assuming these facts and given a quantity of the strong solution, how would you most rapidly prepare a series of solutions of intermediate strengths so as to determine what strength of salt solution would just suffice to cause the freshly split stems to become perceptibly limp?

22. The trunk of an Oak tree, when in full leaf, is sawn all round so deeply as to cut through the sap-wood. State and explain the effect of this operation.

23. Describe the features seen in a cross-section of a piece of wood (*e.g.* of oak or ash) when examined with a lens. Illustrate your answer by means of a diagram.

24. Explain the nature and mode of origin of "knots" and of "silver grain" in timber.

25. What is meant by a Medullary Ray? Where are medullary rays found, and what are their uses?

26. When the trunk of a dicotyledonous tree is cut across, the wood is seen to be disposed in rings. Explain this fact, and indicate its relation to the age of the tree.

27. Explain why it is easier to split a piece of wood in the direction of the grain than across it.

28. Give an account of the structure and uses of Lenticels.

29. Describe and explain as fully as you can the appearance assumed by a tree growing in a position fully exposed to the wind from the sea.

30. Draw and describe the appearance of the buds either of Beech, Horse-chestnut, or some other tree, during winter. Through what stages do these buds pass in spring? What method would you use to hasten the natural opening of a bud?

31. How can you distinguish by the aid of bark, buds, or general appearance between any six British trees when their branches are bare in winter?

32. Describe as much as you have actually observed of the life-history of the Strawberry. Describe carefully with illustrative sketches, the three kinds of stem this plant possesses, with their respective leaf-structures. How is the plant usually propagated, and how would you treat it through the year to obtain a good supply of fruit?

33. Describe a *rhizome*, a *runner*, and a *tuber* in any examples you may select.

34. Describe the appearance of a shoot which has grown out of a potato in the dark, and account for its peculiarities.

35. Describe two examples of climbing plants. What are (1) the advantages, (2) the disadvantages, of a climbing habit?

36. Describe, with the help of drawings, five different devices or modifications of structure which enable plants to climb. Describe any experiments which you have made with climbing plants.

37. Draw and describe the internal structure of (*a*) a Tulip or other bulb, and (*b*) a Crocus or other corm. Explain exactly how you can best get such plants to grow healthily indoors during the winter months.

38. Describe the life-history of (*a*) a Crocus and (*b*) a Tulip, as usually propagated, distinguishing carefully between the "shoot-generations" belonging to different years. In what fundamental respects do these two plants agree? Mention four other plants of similar habit.

39. Write a short account of the chief modes of vegetative propagation occurring in wild plants. Illustrate each method by one example.

40. Contrast the mode of storage of reserve food in a Crocus, a Lily, and a Dahlia.

41. What is starch? Where do you find it in the plant? How would you recognise its presence in a plant (*a*) with the naked eye, (*b*) under the microscope? State exactly what you know of the part played by starch in the economy of the plant.

42. Mention three native annuals that live only during spring. In what kind of habitat do they grow, and what characters have they in common? Mention three other annuals that last till autumn.

43. Give the outlines of a lesson on Transpiration, and state exactly what experiments you would perform, and the conclusions you would draw from each.

44. What materials would you select for the purpose of demonstrating the various modifications of stems, and how would you explain the morphological nature of the objects to a class?

45. What are the chief points on which you would lay emphasis in a lesson on Turgescence? By what experiments would you illustrate the lesson?

46. Explain fully what is meant by Bark, and state the various ways in which it may be formed.

47. What use could you make of the botanical material provided by a vegetable shop during the winter months—*e.g.* Carrot, Turnip, Potato, Beetroot, etc.—to illustrate the form, structure, and living processes of plants?

48. Explain why it is better to prune a vine in the autumn or winter than in the spring.

CHAPTER VI.

FLOWERS AND THEIR WORK.

224. **The Work of the Flower.** We have already examined the Broad Bean flower,* and we have seen that after a time nothing is left of the flower except (*a*) the "young pod," which becomes greatly enlarged and contains the seeds; and (*b*) the calyx, which remains as a cup round the bottom of the pod. Evidently the great work of the flower is the production of seeds. Are any other parts besides the pistil concerned in this work, and, if so, what share do they take in it? You have noticed the yellow powder (pollen) which is produced in the anthers and is set free when they open, and which is then found inside the keel and on the upper parts of the pistil (style and stigma). Has the pollen anything to do with the production of the ripe pod and its seeds? Would the pistil grow into a fruit, with seeds, if no pollen came into contact with it?

Exp. 344. *Effect of removing the Anthers.* Flowers which have not yet opened must be used in these experiments, because the anthers burst and shed their pollen at an early stage. Remove the anthers, making sure that you pick off the whole number, and that none of them have burst already. To prevent pollen from reaching the pistil from another flower, tie a small bag of paper or of fine muslin over the antherless flower, which must, of course, be allowed to remain on the plant. If the removal of the anthers has been carefully done, the flower will open much as usual. Treat several flowers in this way, in case any damage is done which might throw doubt on the results. Are any seeds formed? Leave some of the antherless flowers uncovered; do any of these produce seeds?

Exp. 345. *Effect of removing the Stigma.* You will have noticed pollen adhering to the upper part of the pistil, *i.e.* the style, especially to the tuft of hairs and the little terminal process

* See Ch. I. Art. 7. If flowers of Broad Bean are not available when this part of your work is begun, use those of some other allied plant—*e.g.* Sweet Pea, Gorse.

(stigma) just above it. Is this end part of the style the only part capable of receiving pollen? Open young flowers (with the same precautions as before) and remove the upper part of the style, cutting just below the tuft of hairs; cover some of these stigmaless flowers with small bags, and leave others exposed. Does this affect the result? To meet the objection that the removal of the stigma causes injury which might account for the result, try the effect of opening some young flowers and covering the top of the style with a small bit of plasticine.

225. **Pollination.** The foregoing experiments show that ripe seeds are not produced unless pollen comes into contact with the upper part of the style—that is, unless pollination occurs. Will pollen from the anthers of the same flower bring about the formation of seeds (Exp. 346), or must the pollen come from another flower (Exp. 347)?

Exp. 346. Cover a young unopened flower with a paper or muslin bag, and see whether seeds are produced. Treat several flowers in this way, so as to have a number of results on which to base your inferences.

Exp. 347. Place pollen on the stigmas of newly opened flowers, using a fine brush; dip the brush into boiling water before using it again each time (to kill any pollen left on it) and dry it. In some cases (A) place on the stigma pollen from the anthers of the same flower; in others (B) bring the pollen from another flower on the same plant; in others (C) bring it from a flower on another plant. In the two latter cases (B and C) the flower's own anthers must be removed before they have opened and shed the pollen.

226. **The Essential Organs.** It is now obvious that the only parts of the flower directly concerned in, and essential to, seed-production are the stamens and the pistil. The lowest seed-plants (*e.g.* Pines, Yews, Cycads) have their young seeds exposed (on flat scales in most cases) to the air, instead of being formed within a closed chamber or seed-vessel, as in the bean; and the stalks of the stamens cannot be considered as essential (they remain undeveloped in some plants). The essential structures appear, therefore, to be the anthers and the "young seeds." We know that in the Bean, as in other seed-plants, these "young seeds" do not develop into mature seeds, but perish like the rest of the flower, unless pollen-grains are placed on the stigma. In what way does the pollen-grain induce the young seed to develop into a mature seed? What happens when a pollen-grain is placed on the stigma?

227. **How Pollen is Produced.** The ten stamens arise in the very young flower as ten small outgrowths from the receptacle, and for

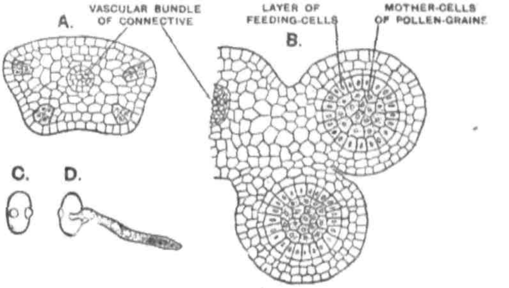

Fig. 77.—A and B, Cross-sections of Young Anthers; C, a Ripe Pollen-grain; D, Pollen-tube.

some time they all grow out independently. The anther at first grows much faster than the stalk, and becomes slightly flattened. Some of the cells in the anther become distinguished from the rest by their large size and dense contents; these cells (shaded cells in fig. 77 A) form four longitudinal masses running through the young anther. They divide actively, and cut off several layers of cells, including a nourishing layer of large cells (tapetum) which surrounds the central mass of "mother-cells." The latter keep on growing and dividing, and eventually they produce the pollen-grains (fig. 77 B). Meanwhile the stalks of the stamens have been growing too, but during their growth nine of them become raised on a common basal "stamen-trough," formed by the tissue of the receptacle (see Exp. 17) growing out as a ridge below these nine stamens and raising them up together. It is wrong to call this a case of fusion. The opening of the ripe anther is due to contraction, set up by loss of water, of the cells forming the *fibrous layer* just within the epidermis

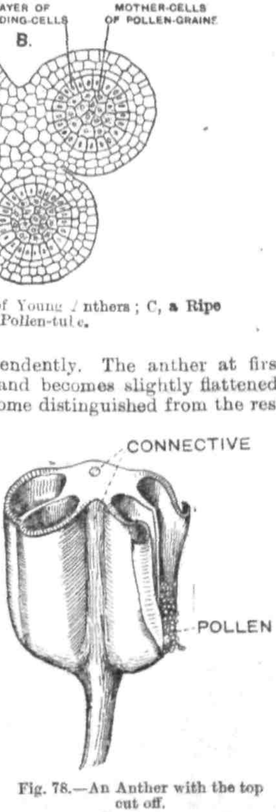

Fig. 78.—An Anther with the top cut off.

The right anther lobe is represented as having dehisced.

(fig. 79). The pollen-grain is a single oval (ellipsoid) cell, with a number of small rounded projections in a row around its equator.

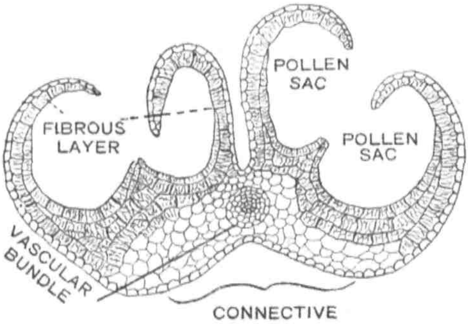

Fig. 79.—Transverse Section of Anther after Dehiscence.

228. **How the "Young Seed" is Produced.** The pistil arises as a ridge shaped like a *horse-shoe*, with the *open side upwards*, at the top of the receptacle of the very young flower. This ridge grows up and becomes a tapering curved plate, whose edges *grow together and form a cavity*, while the tapering end gives rise to the style. Inside the cavity, along a *thickening (placenta)*, which marks the seam (ventral suture) where the upper edges of the horse-shoe joined, there grow out several small projections. Each becomes curved, and points towards the style. Near the apex of the projection, just below the epidermis, a cell becomes larger than the rest (shaded cell in fig. 80 A), and after some divisions, including the formation of some tapetum-cells (fig. 80 B, C), gives rise to a very large cell, the *embryo-sac*. In the embryo-sac several cells are then formed, bnt the only

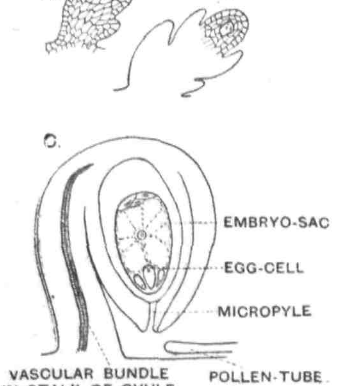

Fig. 80.—Development and Structure of Ovule ("young seed"); Longitudinal Sections.

one that need concern us is a cell near the micropyle end of the sac, which, as we shall see later, is the *egg-cell.* Whilst these changes are going on in the body (nucellus) of the young seed, the apex has curved still more, and the body has become covered by two coats, first an inner and then an outer, which grow up as ring-like ridges from the short stalk of the nucellus, but an opening (micropyle) is left at the apex, just above the embryo-sac.

229. **Stigma and Style.** When the flower has opened, the stigma becomes wet and sticky. This can be more easily seen in flowers with large stigmas, *e.g.* Tulip, as that of the Bean is rather small and obscured by the tuft of hairs below it. This sticky fluid is formed by the cells of the stigma, and oozes out at the surface. The surface-cells of the stigma project as short hairs with thin walls, between which the pollen-grains are held when placed on the stigma. Farther down, the outer cells have thick walls, as have the stiff hairs forming the tuft below the stigma. The inner cells of the stigma have swollen gummy walls, and a central strand of similar cells runs down the style, forming the *conducting tissue.*

Exp. 348. Examine the stigma of a Tulip (or other flower with large stigma), and see whether it is wet. If so, shake over it some powder, *e.g.* flour or chalk, and then try to blow the powder off. Place a stigma on your tongue, and see whether it is sweet. Place a few stigmas in some Fehling's solution in a test-tube, and heat (test for sugar).

Exp. 349. *Growth of Pollen-Tube.* Place some water in watch-glasses and add different amounts of sugar, so as to get solutions varying in strength from about 5 to 30 per cent. Into each place some pollen; try various plants. In the case of the Broad Bean and the Sweet Pea, a 10 per cent. solution is about right, and in an hour, or even less, you will see a slender thread growing from some of the grains; this is the pollen-tube, which resembles a root-hair in appearance. If you have a microscope, fix a ring of cardboard or of plasticine on a glass slide; put a drop of sugar solution on a cover-glass, dust some pollen in it, then invert the cover over the ring. The drop will hang into a closed chamber, thus preventing evaporation, and the growth of the pollen-tubes can be observed with the microscope.

230. **Fertilisation.** The contents of the pollen-grain on absorbing water swell, and then grow out at one of the projections, forming the pollen-tube (fig. 77 D). When this occurs on the stigma, the tube (into which pass the living contents of the grain) grows down the style through the conducting tissue, feeding itself on the cells

it meets in its passage, and on reaching the bottom of the style it grows along the placenta until it reaches the neighbourhood of a "young seed." Then it is attracted to the micropyle, which it enters; the tip of the tube opens on reaching the embryo-sac, and one of the cells it contains passes to the cell already mentioned as occupying the upper end of the sac; then these two cells fuse. The cell coming from the pollen-tube is a male cell *; the cell in the embryo-sac, with which this male cell fuses, is a female cell (ovum or egg-cell). These cells have no cell-walls. This fusion is the act of *fertilisation*; the passage of the pollen-tube to the micropyle is the final stage in the process of pollination (in the Pine and its allies the pollen-grain is deposited on the micropyle).

231. **Results of Fertilisation.** The fertilised egg grows rapidly and divides, forming eventually a thickish stalk (*suspensor*) attached to the upper end of the embryo-sac, and bearing at its free end a rounded mass of cells (*embryo*). The latter soon shows two outgrowths (*cotyledons*) at the lower end, and between these the plumule with its young leaves is developed, while the part nearest the suspensor (and therefore nearest the micropyle) acquires a root-cap and forms the radicle (fig. 81). In many plants the second of the two male cells fuses with a cell in the centre of the embryo-sac, and this fusion is followed by active growth and cell-formation, giving rise to a mass of nutritive tissue (endosperm) around the embryo; but in the Broad Bean the endosperm is quite rudimentary, its cells having no walls, and is soon absorbed. The nucellus is also absorbed by the growing embryo, which soon fills the whole space inside the integuments, and the latter form the seed-coat.

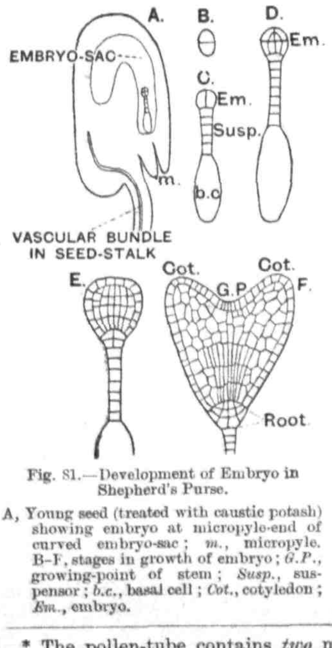

Fig. 81.—Development of Embryo in Shepherd's Purse.

A, Young seed (treated with caustic potash) showing embryo at micropyle-end of curved embryo-sac; *m.*, micropyle. B–F, stages in growth of embryo; *G.P.*, growing-point of stem; *Susp.*, suspensor; *b.c.*, basal cell; *Cot.*, cotyledon; *Em.*, embryo.

Exp. 350. The development of the embryo is easily followed in

* The pollen-tube contains *two* male cells (see Art. 231), and a third cell (vegetative cell) which takes no part in fertilisation.

the Shepherd's Purse, a very common weed which flowers nearly all the year round. Pick flowers from which the outer parts are falling or have just fallen. Open the young fruit and remove the young seeds to a slide, then cover them with a few drops of caustic potash solution. By teasing the seeds with needles, or pressing them under a cover-glass, it is easy to isolate the embryos. Sketch the stages observed (fig. 81).

232. **The Flower-Leaves.** The parts of the flower arise on the receptacle in much the same way that foliage-leaves arise on an ordinary stem, and they may be called flower-leaves. They are crowded together to make the flower as compact as possible, and no internodes or axillary buds are present as a rule. The five calyx-leaves (sepals), after growing independently for a time, are carried up together on a ring-like outgrowth, formed in the same way as the "stamen-trough," which carries up nine of the stamens. The pistil grows from a single pistil-leaf, or *carpel*, which differs from the rest in the growing so as to form a closed cavity. What we have called the "young seed" should not be called a seed until after fertilisation; before that it is better called an *ovule*, since it contains the ovum (egg), and the cavity containing the ovules is better called *ovary* instead of "young pod."

Nature of Pollen-Sac and Ovule. Not only are the pollen-sacs and the ovules the essential parts of the flower, but they differ entirely in nature from the other parts of the flower, and cannot be compared to any other part of the plant. They are in fact *spore-cases*, inherited from the ancestors of the Seed-Plants, represented at the present day by Ferns and Selaginellas. Although ovules typically grow from the folded-over margin of a carpel (see figs. 116, 117), it is futile to compare them to leaflets, and still worse to regard them as having arisen by modification of leaflets. In some plants the ovules are scattered over the whole inner surface of the carpels; in others they do not grow on the carpels at all, but on the flower-axis (receptacle) itself. The seed-plant, like Selaginella and some Ferns, forms spores of two kinds, small spores (pollen-grains) which ultimately produce the male cells, and large spores (young embryo-sac, fig. 80 B, C) which ultimately produce the female cells. The life-history is similar in Bean and Selaginella, except that no seed is formed in the latter. Fuller details are given in larger works—*e.g.* Lowson's Textbook of Botany. From the facts mentioned, however, it follows that (*a*) the stamens and the pistil are not the "female" organs, (*b*) the terms "male" and "female" can only be properly applied to the contents of the pollen-tube and embryo-sac, formed by germination of the smaller spore (microspore) and larger spore (megaspore) respectively, (*c*) the occurrence of flower-leaves intermediate in form between stamens and carpels on one hand and petals or foliage-leaves on the other does *not* imply that pollen-sacs and ovules arose from modified foliage leaves.

233. **Self-Pollination and Cross-Pollination.** In the Broad Bean, as in many other plants, it is found, on making experiments in artificial pollination, that it is better if the pollen comes from a flower on another plant of the same species (*cross-pollination*) than if it comes from the anthers of the same flower or from those of another flower on the same plant. The two latter cases are very similar in their results, and may be both included under the term self-pollination. When cross-pollination occurs, the resulting seeds are generally more numerous or heavier, and give rise to stronger offspring (superior in height, weight, fertility, etc.), than is the case when self-pollination occurs. In self-pollination there is a mixing of practically similar characters, while in cross pollination there is a mixing of more or less dissimilar characters, especially when the plants that produce the male and female cells live far apart and under different external conditions. Also, any useful variation is likely to be transmitted and even strengthened when cross-pollination occurs. There is, therefore, an obvious advantage to the species in securing cross-pollination, and we find many adaptations, some of them very remarkable, which favour cross-pollination and hinder self-pollination.

234. **Variability.** The offspring of a particular plant are never all precisely alike, even when the seeds are germinated under similar conditions and the seedlings planted in the same soil, watered equally, and exposed to the same amount of illumination, wind, etc. Small differences arising spontaneously under such conditions are said to be variations, and are usually only feebly pronounced. Sometimes, however, they are very marked, and they can often be made so by continually selecting and planting the seeds from those plants which show some special peculiarity (= artificial selection). Spontaneous variations sometimes become hereditary, and hence reappear in the offspring produced from seed. If the seeds are the result of cross-fertilisation, this is more likely to occur when both parents exhibit the same variation, but even when this is not the case a certain proportion of the offspring may exhibit the variation in question. Any variations which are of advantage to their possessors will tend to be strengthened and perpetuated, for the more favoured individuals have a better chance of surviving in the struggle for existence. A variety which does not run true to seed may often be propagated by buds, cuttings, and the like—*i.e.* by portions of the parent plant which develop into new individuals.

Variation is often the result of a change in the environment. This is apparently because the new conditions act in a disturbing manner on the plant's constitution. However that may be, the importance of the fact is very great, for, by the selection of advantageous variations, a plant may become adapted to changed conditions. See Ch. IX.

235. **How Pollen is Carried.** Pollen-grains have no power of spontaneous movement. When the anthers are above the stigma, self-pollination may occur (if the two are mature at the same time) by pollen simply falling on the stigma, but for cross-pollination the grains must be carried to the stigma of another flower by water, wind, or animals. Water-pollination occurs only in water-plants, and only in a few of these. In this country insects are the only animals concerned in carrying pollen from flower to flower.

236. **Mechanism of Broad Bean Flower.** Here cross-pollination is brought about by bees, which may be seen at work on the flowers if you watch plants growing in the open during fine weather. Wind-pollination is out of the question in this case, since the stamens remain enclosed in the keel. When a bee alights on the flower it stands on the two wing-petals, which bend down under the weight of its body. Since the wings are jointed with the keel, the latter is also pressed down. If you carefully watch the bee at its work, or imitate its action by pulling down the tip of the keel, you will see that when this happens a mass of pollen is brushed out of the keel by the tuft of hairs on the style, and the stigma projects from the keel as well. Some pollen is deposited on the bee's hairy body, which also rubs against the stigma; if the bee has visited another flower previously, some pollen will be left on the stigma. When the bee leaves the flower the keel rises to its former position, and the process may be repeated a few times when other bees visit the flower.

237. **Attractions of Broad Bean Flower.** Why does the bee visit this flower? Notice the long tongue (proboscis) which the bee pokes into the lower part of the stamen-trough below the free stamen. It is easy to see this if

you pull off the standard and carefully watch the next bee that comes to the flower. What does the bee find here? Take a newly opened flower and remove the calyx and corolla, then pull apart the stamen-trough and the pistil, and notice the liquid which has collected at the bottom of the trough around the base of the ovary. By tasting, or by the Fehling's solution test, one finds that sugar is present *in this liquid—the honey, or nectar*—which is produced by gland-cells at the base of the stamen-trough. The bee is guided to the flower, in its search for honey, by the white corolla (easily distinguished among the foliage, and made more conspicuous by the velvety black spot on each wing-petal) and also by the fragrant odour, which is emitted by the petals (and by the honey itself to a slight extent). The coloured streaks on the standard no doubt help to guide the bee to the opening below the free stamen; but its removal does not prevent a bee from finding this opening, as can easily be seen by making the experiment. Since the honey can only be reached when the keel is pressed down with some force, and is produced at the bottom of the tube formed by the stamen-trough (closed above by the free stamen and the standard), it can only be reached by an insect with a heavy body and a fairly long tongue. The flower is specially adapted to the visits of bees, especially the larger- and longer-tongued kinds, the hive-bee and humble-bee, and without their aid cross-pollination would not take place at all. Sometimes a humble-bee working at the flowers is seen to bite through the calyx-tube and insert its tongue through the hole thus made, thus reaching the honey without entering the flower in the "proper" way, *i.e.* from the front. Many other "bee-flowers" (*i.e.* flowers specially adapted for bees' visits) show neat, round holes made by the humble-bee in its short cut to the honey, of which it robs the flower without rendering any service in return.

238. **Contrivances and Conditions favouring Cross-Pollination.** There are in flowers many forms, conditions, and mechanisms, the significance of which becomes clear only on the view that cross-fertilisation is advantageous, and that the

flowers have become adapted to it. Such mechanisms, etc., either entirely prevent self-pollination, or tend to do so, and are distinct adaptations for cross-pollination. Neglecting cases where the position of anthers and stigmas prohibits autogamy, we shall consider some of the more striking conditions. In many plants cross-pollination is absolutely necessary if seed is to be produced, owing to the flowers being unisexual. We have this condition in its extreme form where the staminate and pistillate flowers are on different plants (Willow). **Dichogamy** is a condition in which, though the flowers are hermaphrodite, the anthers and stigmas come to maturity at different times, and which when completely developed entirely prevents self-pollination. There are two kinds of dichogamy: (*a*) **protandry**, where the anthers ripen first; here the pollen grains are transferred to an older flower: (*b*) **protogyny**, where the stigma ripens first; here the pollen grains are transferred to a younger flower. Protandrous flowers are much more common than protogynous. Examples of the former are found in Compositæ, Labiatæ, etc.; of the latter in Arum, most grasses, Plantago, Paeony, etc. Most wind-pollinated flowers are protogynous.

Wind-pollinated and insect-pollinated flowers have each special characters of their own, so that as a rule we can distinguish them at a glance. In wind-pollinated flowers the pollen is produced in great abundance, as much of it must be wasted; the flowers are small and inconspicuous; there is no honey or perfume; and frequently the stigmas are branched and feathery, to catch the pollen grains. The greatest variety, however, is shown in insect-pollinated flowers; there is no difficulty in recognising these as being the most highly specialised. As a rule they have large, conspicuous, or highly coloured corollas, or are arranged in conspicuous inflorescences; they usually secrete honey and give out perfume. The pollen is not produced in any great abundance, as the provision for its transference is more perfect. The bright corollas, the perfume and honey, serve to attract insects. To understand this, the student must remember that insects do not visit flowers for nothing.

They go in search of food. In return for the service rendered by insects the flowers sacrifice part of their nutritive substance in providing food to the insects (honey and pollen), and make a further sacrifice of energy in developing certain structures (corollas) which will attract the insects. By instinct insects associate these attractive structures with the presence of a supply of food-material.

Many insect-pollinated flowers are further characterised by the presence of ingenious mechanical devices, which guide and control the movements of the insect and turn them to the best account. Thus, in many cases, the corolla is so modified that the insect must alight on the flower or enter it in a special way (*e.g.* Labiatae, Papilionaceae); the same result may be attained by the secretion of nectar into special receptacles or spurs (*e.g.* Violet); often the insect, on entering a flower, pushes against special processes or outgrowths which move the stamens and bring the anthers in contact with its body (Sage); or the stamens may be jerked, and the pollen scattered over the insect's body. The general result of all these devices is that the insect receives the pollen on a special part of its body, and when it enters another flower the pollen is deposited on the stigma. In many protandrous flowers this is secured by the style bending over so that the stigma is in the position formerly occupied by the stamens. A very special, but at the same time very simple, arrangement for making the best use of the insects is the condition known as **heterostyly**. It is seen in the Primrose. Here there are two types of flower borne on different plants. One kind has long stamens (with anthers in the throat of the corolla tube) and a short style; the other has a long style and short stamens; thus in the two types the positions of anthers and stigma are simply reversed. Evidently pollination will be most readily effected by transference between these two forms, and not between two flowers of the same form; and experiment has proved that the best seed is produced when this is the case. In the Primrose there are two kinds of flower; this is the dimorphic form of heterostyly. In Lythrum there are three—*i.e.* flowers with long, short, and medium stamens; this is the trimorphic form.

239. **Special Arrangements for Self-Pollination.** Many annual plants cannot afford to undertake the risks and sacrifices attendant on cross-pollination, and are commonly self-pollinated (*e.g.* Groundsel, Chickweed). They have small flowers, often without honey or smell, and are either **homogamous**—that is, their anthers and stigmas mature at the same time—or *so slightly dichogamous that self-pollination is secure.* Even in flowers evidently adapted for cross-pollination there is commonly the possibility of self-pollination as a final resource. Many of them are distinctly dichogamous, but not completely so, there being usually a short period during which self-pollination becomes possible. To effect this there are sometimes special contrivances, such as the curling back of the stigmas to reach the pollen (*e.g.* Compositae, Campanulaceae). A very special adaptation for self-pollination is the production of **cleistogamous flowers.** These are closed flowers produced late in the year by certain plants which had previously produced entomophilous flowers—*e.g.* the Sweet Violet, the Wood Sorrel, *Lamium amplexicaule* (one of the Dead-nettles), etc. In these plants the ordinary insect-pollinated flowers frequently fail to produce seed. The cleistogamous flower is small and inconspicuous. The calyx never opens, and the stamens and pistil are developed in a closed case.

240. **Functions of the Calyx.** The calyx has three important uses in the Bean-flower. (1) It protects the inner parts of the young flower. In the bud, the stamens and pistil are enclosed in the keel, the wings are folded over the keel, and the standard over the wings, and the calyx is wrapped over the outside of all. (2) When the flower opens, the corolla expands, pushing aside the calyx-lobes then the standard curves upwards, and the flower is ready for the visits of bees. The calyx then serves to hold the petals together and prevent their falling apart. (3) The calyx also protects the young fruit to some extent from becoming dried up.

Exp. 351. Remove the calyx from (1) a flower-bud, (2) a newly opened flower, (3) a young fruit, and note the result in each case.

241. **Functions of the Corolla.** We have seen how the standard and the wings help in attracting bees to the flower, and how the wings work with the keel in causing the bee to carry away pollen as well as to bring pollen from other Bean-flowers to the stigma. The keel by enclosing the stamens prevents rain from spoiling or washing away the pollen, and protects it from being shaken out of the flower by wind; it also prevents the nectar from being reached by useless insects, from loss by evaporation, and from being diluted or washed out by rain. The protection of the nectar is made still more complete by its being formed inside the stamen-trough.

242. **The Bean Family.** The family to which the Broad Bean belongs is one of the largest, and also one of the most useful, among flowering plants. The family as a whole is characterised by the fruit being, with rare exceptions, a pod (legume), whence its name Leguminosae. In the great majority of the species, forming the sub-family Papilionaceae,* the flower has the same general structure as that of the Broad Bean. There are two other sub-families not represented in Britain; one of those includes the Acacias and the Sensitive Plant (*Mimosa*, fig. 54). The family includes trees, shrubs, creeping plants, climbing plants, erect herbs, annuals, and perennials; the leaves vary greatly in form, etc. The Papilionaceae are easily recognised by their flowers. Examine all the plants of this type that you find growing wild or in cultivation.

Here is a list of a few common plants to study, making notes and sketches of your observations: Laburnum,† Robinia ("False Acacia"), Wistaria, Gorse, Broom, Kidney Bean, Scarlet Runner, Eating Pea, Sweet Pea, Lupin, Clover, Bird's-foot Trefoil, Rest-harrow, Vetches, Yellow Vetchling, Tares, Sainfoin, Lucerne, Hedysarum ("French Honeysuckle").

Exp. 352. *Flower-Mechanisms in Papilionaceae.* Notice any differences in the calyx (are the lobes equal or unequal in length,

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* So named from the somewhat fanciful resemblance of the corolla to the wings of a butterfly (*papilio*).

† All parts of the Laburnum are poisonous, especially the seeds.

smooth or hairy, etc. ?) ; the corolla (how are the wings jointed with the keel ? How much union is there between the two keel-petals ?) ; the stamens (is the posterior stamen joined with the others so as to form a complete stamen-tube, or is it free ? Are the filaments equal or unequal in length ?) ; the pistil (length of style, its position within the keel, presence or absence of hairs). In each case sketch all the parts carefully (sketch the separated parts and a longitudinal section of the flower), and find out what happens when the keel is pressed down ; if possible, watch bees at work on the flowers. The following notes on the chief types of flower-mechanism may be useful :

(*a*) Stamens and stigma emerge from keel when it is depressed, and return inside it again when the bee flies away ; the same flower may therefore be visited several times : Clover, Sainfoin, Laburnum, etc.

(*b*) Keel-petals joined above as well as below, leaving a small opening at the tip ; pollen shed into upper end of keel before flower opens ; five of the stamens have filaments thickened below the anthers, and the piston thus formed pushes out some of the pollen each time the keel is depressed : Bird's-foot Trefoil, Lupin, etc.

(*c*) Upper edges of keel-petals at first joined, and pollen forced out at tip, as in *b*, but later on the keel splits open, and stigma emerge as in *a* : Rest-harrow.

(*d*) Like Broad Bean, with tuft of hairs on the style which sweeps the pollen out of the keel when the latter is depressed : most Vetches and Peas (fig. 82).

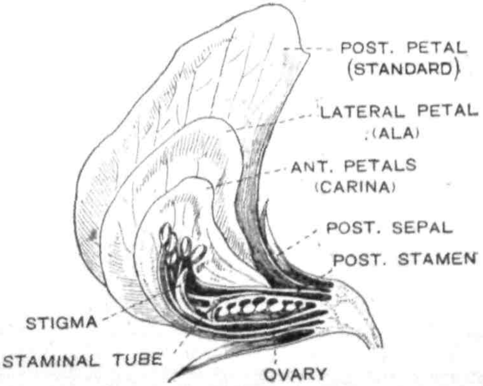

Fig. 82.—Median Section, Flower of Garden Pea.

Ala = wing-petal, carina = keel.

(*e*) Mechanism as in *d*, but stamens and style long and coiled up within a coiled keel: Kidney Bean, Scarlet Runner.

(*f*) Stamens and style tightly held, more or less coiled up, in the keel under tension, and springing out violently when keel is depressed: Gorse, Broom; Lucerne and other Medicks (Medicago).

Exp. 353. *The Buttercup Flower.* In a Buttercup, note the five green sepals; the five petals alternating with these, each with a honey-scale at the base; the numerous stamens; the numerous carpels, each having a small thickened or hook-like stigma (fig. 83). All these parts are inserted independently on the receptacle, which is merely the expanded knob-like end of the flower-stalk. The flower is regular—*i.e.* can be divided by several (how many?) vertical planes into similar halves; that of Bean is

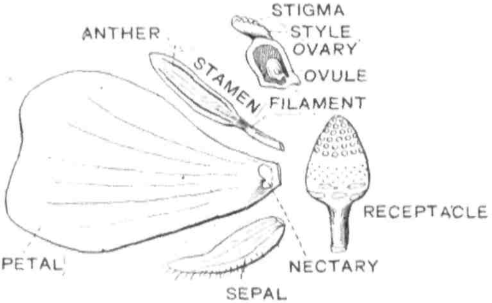

Fig. 83.—The Parts of a Buttercup Flower.

The points of insertion of the different parts are diagrammatically represented on the receptacle.

irregular—*i.e.* there is only one plane of symmetry. There is no *cohesion*—*i.e.* the receptacle-tissue does not grow up and raise the members of a series of flower-leaves on a basal outgrowth (compare sepals and stamens of Bean); the carpels contain each a single ovule, attached to the bottom of the ovary. The flower is shallow, accessible to all kinds of insects, which visit it for the abundant pollen as well as for the honey (only slightly concealed by the outer stamens). Examine flowers of different ages; the outer stamens have shed their pollen while the inner ones are still bent over the carpels, covering the stigmas, which are not exposed until all the stamens have moved outwards, and most of them have set the pollen free to be carried away by insects. The "male stage" and the "female stage" thus overlap for some time, during which self-pollination is possible.

243. **The Buttercup Family.** Examine flowers of other plants belonging to this family (Ranunculaceae).* Lesser Celandine has flowers like those of Buttercup (note number of sepals and petals, closing of flower in bad weather). In Wood Anemone there are numerous carpels and stamens, then a series of white spreading leaves (do these bear nectaries?), and outside of these, a little below the receptacle itself, there is a series of green divided leaves. In Pasque-flower (*Anemone pulsatilla*), outside of the stamens we find a series of small honey-scales, then a series of large blue leaves which stand up and, together with the stamens, conceal the honey from short-tongued insects, *e.g.* flies. The Wood Anemone is visited by insects of all kinds for its pollen, but the Pasque-flower is visited chiefly by bees for honey; the former begins flowering in April, the latter about a month later, when more bees are on the wing. The Meadow Rue has numerous small flowers;

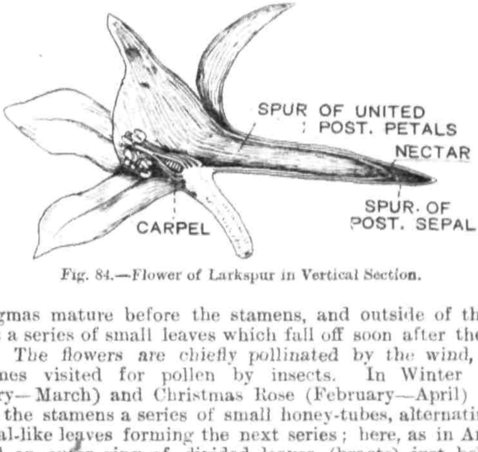

Fig. 84.—Flower of Larkspur in Vertical Section.

the stigmas mature before the stamens, and outside of the latter there is a series of small leaves which fall off soon after the flower opens. The flowers are chiefly pollinated by the wind, though sometimes visited for pollen by insects. In Winter Aconite (January—March) and Christmas Rose (February—April) we find outside the stamens a series of small honey-tubes, alternating with the petal-like leaves forming the next series; here, as in Anemone, we find an outer ring of divided leaves (bracts) just below the flower. In Wild Clematis (July—August) there are no nectaries, and only *one series of flower-leaves outside the stamens*; *it is a* pollen-flower, like Wood Anemone. Marsh Marigold (March—May) also has only one series of outer flower-leaves (golden yellow), but honey is produced by the bases of the carpels; like Buttercups, it is visited by various insects for honey and pollen. All the flowers mentioned thus far have either no honey and are visited for pollen,

* See Appendix III. for characters of families.

or have the honey only slightly concealed so as to be out of the reach of the smaller insects. The comparison of these flowers suggests that most of them have not yet developed petals, whose attractive function is assumed by the coloured (petaloid) sepals, or that petals may have been derived *from the outermost stamens*, or that sepals may have evolved from foliage-leaves growing just below the flower. Perhaps the flowers of this family are still in course of evolution; at any rate, very few show the distinct sepals and petals of a "typical flower." In the next flowers to be mentioned, the "sepals" are petaloid, the "petals" bear curious nectaries, which can only be reached by long-tongued bees; the flowers open in summer, when bees are plentiful, are visited chiefly by humble-bees, and usually have the rich blue colour characteristic of so many "bee-flowers." In Columbine, each petal bears at its base, on the outer side, a long tube (spur), at the end of which there is a nectary; the flower-stalk is curved, so that the flower hangs down, and the spurs are curved at the ends (this prevents the honey from dropping out, and the drooping of the flower protects pollen and honey from rain). This type leads to others in which the flower is irregular, and insects can only enter in one particular way. In Larkspur (fig. 84), the large posterior sepal has a long spur at its base; into this project two processes from the two upper petals, which are pressed together so as to form a tube above and a solid mass (nectary) below, and the entrance to this elaborate honey-pocket is narrowed by the two side-petals * (which act as "honey-guides") and by the stamens which move up into the mouth of the opening in turns as they mature. In Monkshood (fig. 85) the posterior sepal † forms a large hood covering the two posterior petals,

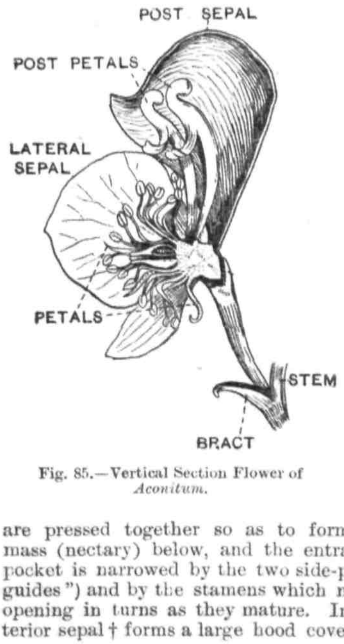

Fig. 85.—Vertical Section Flower of *Aconitum*.

* These are absent in some species of Delphinium.

† There is a posterior or uppermost sepal in nearly all the families of Dicotyledons, the Papilionaceae forming the only important exception.

each of which consists of a stalk carrying a nectary with a tube whose opening faces downwards. The humble-bee often bites through the petal-spurs of Columbine and the hood-sepal of Monkshood, but the thick double-walled spur of Larkspur seems to prevent this. These three flowers are fine examples of adaptation to a special insect-visitor; the pollen and honey are sheltered from rain, and the honey can only be reached by a large and long-tongued bee. The limit of distribution of the Monkshoods (*Aconitum*) closely follows, and is just within that of the humble-bee (*Bombus*).

244. **The Wallflower Family.** In the Wallflower, note the arrangement of the flowers in a raceme (fig. 87), but without any bracts. The four free erect sepals, an outer and an inner pair, the outer ones bulged at the base; the four free petals, each having a long, narrow, erect lower part (claw) and a broad, spreading upper part

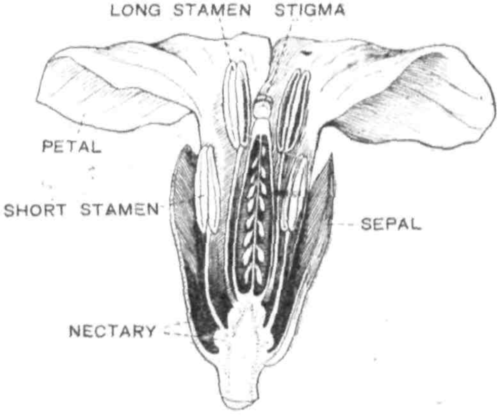

Fig. 86.—Vertical Section of Wallflower.

(limb); the two outer short stamens and the four inner long ones; the cylindrical ovary with two rounded stigma-lobes on a very short style (fig. 86). Note the nectaries at the bases of the outer stamens. The honey can only be reached by insects with long tongues, *e.g.* bees; they stand on the platform made by the spreading petal-limbs, and in probing for the honey rub against the anthers and stigma. In many members of the Wallflower family (Cruciferae) the lower flowers of the raceme tend to grow up, by lengthening their stalks, so as to bring all the flowers together; this makes them more conspicuous. When the flowers all reach the same level, as in

Candytuft, the inflorescence is called a *corymb* (fig. 88). In the outermost flowers the outer petals have larger limbs, making the corollas irregular and increasing the conspicuousness of the inflorescence. When the flower-tube (formed by the sepals and the petal-claws) is short, the flowers are adapted to short-tongued

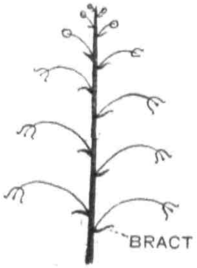

Fig. 87.—A Simple Raceme.

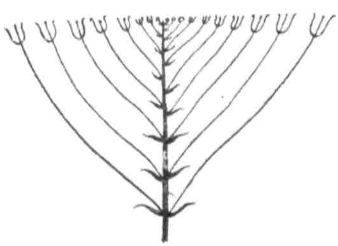

Fig. 88.—A Corymb.

insects (flies, beetles). The Shepherd's Purse, which flowers all the year round, is usually self-pollinated; at any rate, in the winter months.

Examine also other members of this large and easily recognised family—*e.g.* Lady's Smock, Hedge Mustard, Water-cress, Honesty, Stock, Charlock, Turnip, Cabbage, Cauliflower.

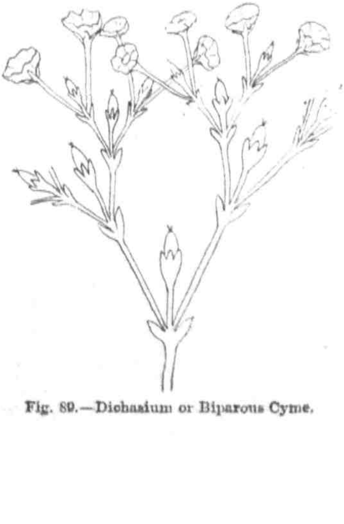

Fig. 89.—Dichasium or Biparous Cyme.

245. **The Pink Family.** Easily recognised by the vegetative characters (leaves in crossed pairs on swollen nodes of the stem) as well as by the inflorescence and flower. The main axis of the inflorescence ends in the first-formed (oldest) flower, and gives off a branch on each side below this flower; each branch then repeats the process, and so on, giving rise to a *dichasium* or *dichasial cyme* (fig. 89). The petals are free, the stamens typically twice as many as the petals, and the ovary bears from two to five styles,

each with a hairy stigmatic surface along its inner side. There are two well-marked types of flower in this family (*Caryophyllaceae*): (*a*) those having the sepals free, or joined to a very short ring outgrowth; (*b*) those having the sepals carried on a long tube.

(*a*) Flowers of the first type are shallow and open, accessible to, and chiefly visited by, short-tongued insects. In *Arenaria*, which includes the Sea Purslane (common on sandy shores, with fleshy leaves) and the Sandwort, the petals are undivided, and the full number of stamens (in two series) is usually present; in *Stellaria* (Stitchwort and Chickweed) and *Cerastium* (Mouse-ear Chickweed) each petal is notched, and the stamens often fall short of the full number. In Stitchwort (*S. holostea*) the outer stamens mature first and bend towards the centre of the flower, then the inner stamens mature, then the styles curl over so as to touch the inner stamens, making self-pollination possible as a last resort. In Chickweed (*S. media*), which flowers all the year round, the stamens and styles mature at the same time, and self-pollination often occurs. The flowers produced in winter usually remain closed, are self-pollinated, and have only three stamens as a rule (compare with cleistogamic flowers of Violet).

(*b*) In the second type of flower, seen in the Campions and their allies, the flower has a deep calyx-tube which holds the clawed petals together, so that the honey can only be reached by long-tongued insects. In most cases there is a scale (ligule) where the vertical claw of the petal joins the horizontal limb (compare this with the Wallflower), and the collar formed by these scales round the mouth of the flower (which is further blocked by the stamens and styles) prevents small insects from crawling down to the honey. In most of the British species of *Lychnis* and *Silene*, the tube is at least $\frac{1}{2}$ in. long, and the flowers are pollinated chiefly by butterflies and moths. In Ragged Robin the tube is short enough for bees or even long-tongued flies. The Red Campion (*Lychnis dioica*) is largely pollinated by butterflies; the humble-bee often bites through the calyx-tube. The white flowers of the White Campion (*L. vespertina*) open at night and then become strongly scented, and are pollinated by night-flying moths. The Red and White Campions cannot be self-pollinated, for as a rule the flowers on each plant have either the stamens or the pistil undeveloped; the "female" plants are generally larger and more robust in growth than the "male" plants (why?).

246. **The Rose Family.** The chief feature which distinguishes this large family from the Buttercup family is the presence of what is often wrongly called a "calyx-tube." If you imagine a Buttercup flower in which the receptacle, during the development of the flower-parts, grows up at the sides as a ring which carries on its edge the sepals, petals, and stamens, leaving the carpels on the central knob, you would have a flower like that of a Cinquefoil, Strawberry, or Blackberry (fig. 90). Since the sepals are the first

parts to be developed, the cup-like outgrowth involves them more than the other parts, which can easily be detached from the cup.

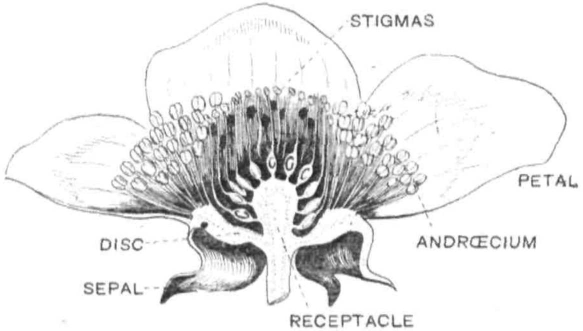

Fig. 90.—Vertical Section, Flower of Blackberry.

This upgrowth of the receptacle not only tends to enclose and protect the carpels, but also makes the flower tubular and conceals the

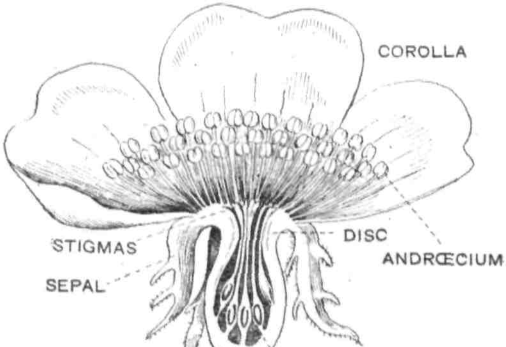

Fig. 91.—Vertical Section, Flower of Dog Rose.

honey to some extent. There is usually a honey-disc within the bases of the stamens (fig. 90); but the Dog Rose (fig. 91) has no

honey, and is a "pollen-flower," the stamens being numerous (as in most Rosacae). In the Apple (fig. 92), Pear, and Hawthorn the receptacle-cup grows up closely around the carpels, and later on becomes joined to them. Examine also the flowers of Avens, Raspberry, Cherry, Sloe, Agrimony. Wind-pollination occurs in the Salad Burnet (common on dry, chalky downs), which has small flowers (June — August) in mop-like clusters. Each cluster is made up of a dense mass of both male and female flowers, each of which has a calyx of *four sepals*. The former have many anthers well exposed to the wind on long filaments, and the latter a tufted stigma mounted on a long style. In this case there is also a provision for preventing the pollination of the female flowers by the anthers of the same cluster; for, not only do the female flowers occupy principally the upper part of each cluster with the male flowers below them, but the latter open later than the former, and distribute their pollen after the females of the same cluster have been pollinated.

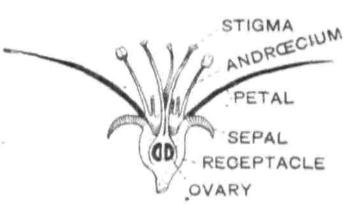

Fig. 92.—Diagrammatic Vertical Section, Flower of Apple, showing the Inferior Ovary and two of the Stamens.

247. **The Umbellifer Family.** This family gets its name (Umbelliferae) from the characteristic grouping of the flowers in *umbels*.

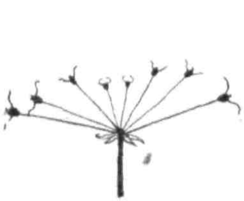

Fig. 93.—A Simple Umbel.

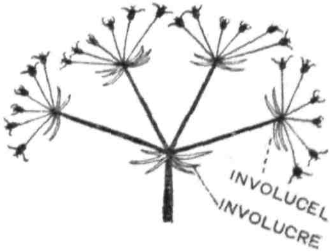

Fig. 94.—A Compound Umbel.

Umbels occur in other families, and some Umbelliferae have other kinds of inflorescences—*e.g.* heads in Sea Holly. The simple umbel (fig. 93) resembles a corymb, in which the main axis remains undeveloped between the flower-stalks, so that the latter all arise from one point. This is found in a few Umbelliferae (also in Cherry Ivy, etc.); but in most cases a *compound umbel* (fig. 94) is formed

by each branch producing an umbel of flowers instead of a single flower. The result is a conspicuous massing of the individually small flowers; the flowers all open almost at the same time, and the outer ones have irregular corollas (as in a corymb). Why is it better for the plant to produce numerous small flowers and mass them together in this way than to produce a few large flowers? Examine the flowers of Cow Parsnip, Fool's Parsley, or any other Umbellifer, and notice the five free petals (how do those of the outer flowers differ from those of the central ones?); the sepals are small or absent (how, then, are the flower-buds protected?); the five stamens

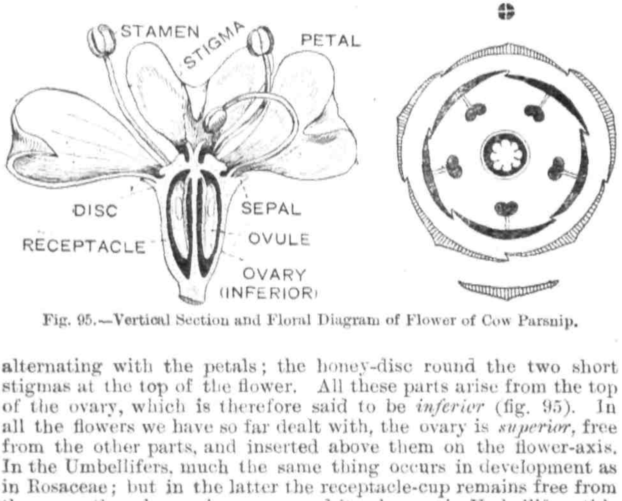

Fig. 95.—Vertical Section and Floral Diagram of Flower of Cow Parsnip.

alternating with the petals; the honey-disc round the two short stigmas at the top of the flower. All these parts arise from the top of the ovary, which is therefore said to be *inferior* (fig. 95). In all the flowers we have so far dealt with, the ovary is *superior*, free from the other parts, and inserted above them on the flower-axis. In the Umbellifers, much the same thing occurs in development as in Rosaceae; but in the latter the receptacle-cup remains free from the ovary though growing up around it, whereas in Umbellifers this cup begins to develop at an earlier stage, and carries up the carpels as well as the other parts and forms the side-walls of the ovary, which is roofed in above by the carpel-leaves. The honey is freely exposed, so that insects with short tongues can lick it, and the flowers are chiefly visited by flies and beetles. We have already seen that many flowers are *protandrous*—*i.e.* the stamens mature and shed their pollen before the stigmas are ready to receive pollen, though as a rule there is a period during which self-pollination may occur. The majority of Umbellifers are extremely protandrous; usually all the stamens in an umbel have shed their pollen and withered before any of the stigmas expand to receive pollen. In this way self-pollination is prevented.

248. **The Labiate Family.** Plants with leaves in crossed pairs on a square stem (which leaves on an erect shoot have the longest stalks, and why?); dig plants up and notice their mode of spreading underground. In White Dead-nettle, note the arrangement of the flowers in clusters in the leaf-axils, and make out the order in which

Fig. 96.—*Dead-nettle, showing two Clusters of Flowers.*

the flowers of each cluster open (figs. 96, 97); the calyx-tube (*gamosepalous*); the corolla-tube with distinct upper and lower lips (the upper forming a hood to protect pollen and honey from rain, the lower a platform for bees to stand on). Open up the corolla, and note the four stamens in two pairs (how do the pairs differ? what is peculiar in shape of anthers?); the long style, forked above into two stigmatic lobes; the four-lobed ovary; the honey-gland round base of ovary; the ring of hairs near bottom of corolla-tube (use of these hairs?). This flower (fig. 98) is chiefly visited by humble-bees (how is it adapted for their visits?). Which is first touched by the bee's head—the stigma or anthers? Most Labiates are bee-flowers, and all show the same general structure as the White Dead-nettle, differing in details. Some have shorter tubes—*e.g.* Red Dead-nettle, which is visited by small bees. Most are distinctly protandrous; some (*e.g.* Thyme) have female flowers with rudimentary stamens, in addition to complete flowers. In some cases the upper lip of the corolla is very short—*e.g.* Wood Sage, Bugle; examine these flowers, and find out how the pollen and honey are protected against rain. The true Sage (*Salvia*) has only two stamens (fig. 99), and the connective (*c*) of each forms a long curved bar, at whose lower end the barren anther-lobe (*b*) joins with that of the other stamen to form a plate

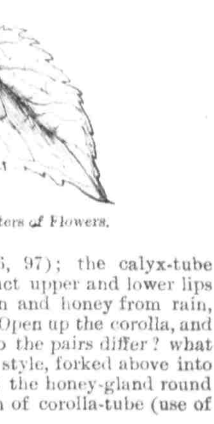

Fig 97.—Diagram indicating the relation of Flowers in half of a Verticillaster

which blocks the way to the nectar. When a bee pushes against this plate, the stamens swing on the filaments as on hinges, and

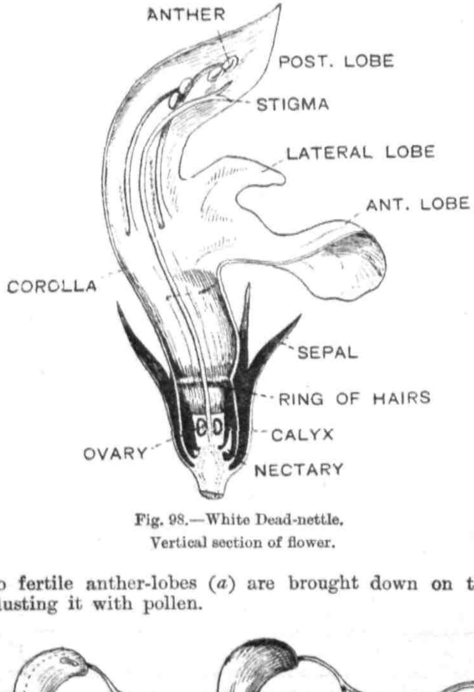

Fig. 98.—White Dead-nettle.
Vertical section of flower.

the two fertile anther-lobes (*a*) are brought down on the bee's back, dusting it with pollen.

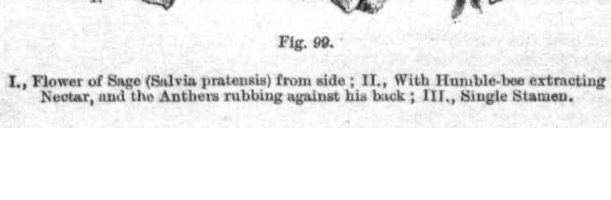

Fig. 99.

I., Flower of Sage (Salvia pratensis) from side; II., With Humble-bee extracting Nectar, and the Anthers rubbing against his back; III., Single Stamen.

249. **The Foxglove Family (Scrophulariaceae).** Flower usually with a two-lipped corolla and two pairs of stamens, but distinguished from Labiates by the two-chambered ovary (with numerous ovules),

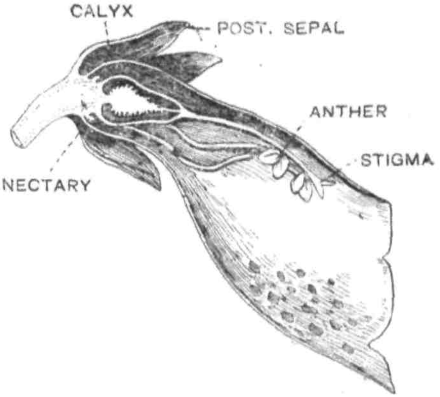

Fig. 100.—Vertical Section, Flower of Foxglove.

also by the usually alternate leaves on a rounded stem (but some have square stems and crossed pairs of leaves). In Mullein, the short-tubed flower (corolla-lobes regular, stamens five) is adapted to flies and short-tongued bees. Speedwell has a similar flower, with a

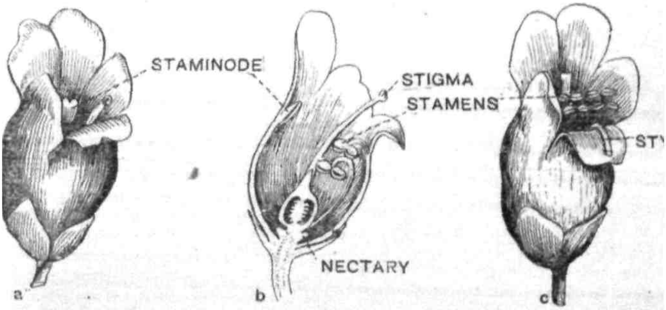

Fig. 101.—Scrophularia nodosa (Figwort).

a, Flower when first opened; b, Longitudinal section of same; c, Flower day or two later. In c the style and stigma are now withering, while the anthers are exposed and about to open.

very short corolla-tube and two stamens, and the chief visitors are hover-flies which alight on the projecting stamens. In most cases, however, the tube is long, and the flowers are chiefly visited by bees and wasps. The tube may be wide-mouthed (*e.g.* Foxglove, Figwort), or closed by two pouched lips (*e.g.* Snapdragon, Toadflax); in Toadflax the corolla has a spur at the base in which honey collects. Figwort, which is largely visited by wasps, is *protogynous*. In the newly opened flower (fig. 101) the style lies in the mouth of the corolla above the lower lip, but the anthers are still closed and hidden in the corolla-tube, the filaments being curved; next day, or a little later, the style withers and falls on the front of the corolla. The female stage is now over, and, unless cross-pollination has occurred, no seeds are formed. Then the filaments unbend, bringing the anthers up to the position formerly occupied by the stigma, and a bee probing for the honey at the base of the corolla-tube is dusted with pollen, which it may then carry to the stigma of a younger flower. In the Musk or Monkey-flower, notice the curious stigma, with two flat lobes. What happens if the stigma is touched on the inner surface, and how will this help in regard to pollination?

250. **The Composite Family.** Here the flowers are small and arranged in a *head* (*capitulum*). It resembles an umbel in which the flowers have no stalks, but are sessile on the flowering stem, whose end is therefore expanded into a disc; the youngest flowers are in

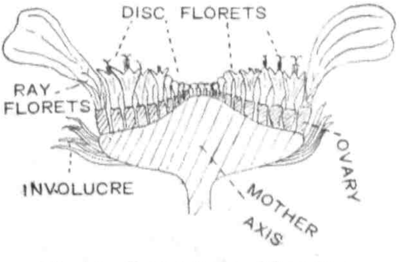

Fig. 102.—Vertical Section of Capitulum.

the centre of the disc, and at the margin, outside of the oldest flowers, there is a series of bracts, which protect the developing florets, and in some cases close over the head at night or in bad weather (fig. 102). In some cases, smaller bracts occur on the disc between the flowers. In an individual flower (figs. 103, 104) note the inferior ovary; the presence or absence of a calyx, its form when present; shape of corolla (whether *tubular* with five lobes at mouth of tube, or *ligulate*—*i.e.* having the mouth drawn out on one side into a strap-like process); the five anthers united to form a tube around

the style; the filaments free from each other, but inserted on corolla; the forked style, with stigmatic surface on inner side of each fork. Study examples of the three types of flower-head, with (*a*) all the flowers tubular, (*b*) all the flowers ligulate, (*c*) outer flowers ligulate and inner ones tubular. Examine the flowers of Cornflower, Knapweed, Thistle, Coltsfoot, Groundsel, Dandelion, Hawkweed, Chicory, Daisy, Sunflower, Marigold, Chrysanthemum. Watch a Dandelion flower-head, and note exactly what happens, day by day, from the time the head first opens until the fruits are ready to be carried

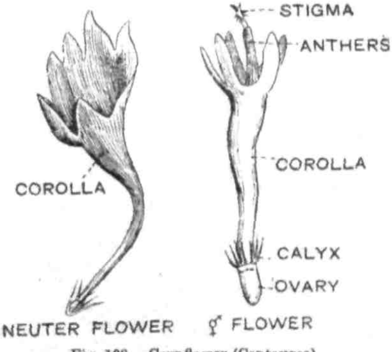

Fig. 103.—Cornflower (Centaurea).
I., Outer neuter flower; II., Tubular hermaphrodite flower.

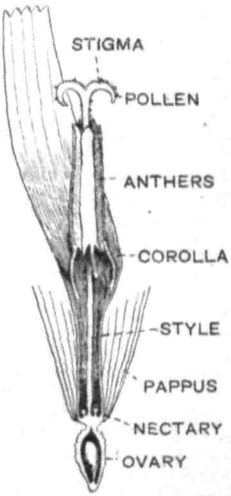

Fig. 104.—Flower of Dandelion.
Basal part cut in section.

away by the wind. Open up flowers of different ages, and note that at first the style is low down in the tube formed by the united anthers, the two lobes being in close contact by their inner (stigmatic) surfaces; the pollen is shed inside the tube, and is swept out of the top by the hairs on the style as the latter grows up. Then the style emerges and its two lobes diverge, exposing the stigmas; if cross-pollination does not occur, the lobes may curve back until the stigmas touch the pollen still adhering to the style, thus bringing about self-pollination. In most composites the corolla-tube is fairly long, and the honey (produced by a nectary round the base of the style) can only be reached by long-tongued insects (bees, wasps,

butterflies, moths); when the tube is short (Yarrow, Daisy, etc.) the flower is visited largely by flies. Groundsel, which flowers all the year round, is chiefly self-pollinated (compare Chickweed, Shepherd's Purse). Which of the plants mentioned in the above list have in their flower-heads (*a*) sterile flowers with neither stamens nor style; (*b*) flowers with complete pistil but no stamens; (*c*) flowers with stamens and a style which acts as a pollen-brush but has no stigmas?

251. **The Lily Family (Liliaceae).** These are perennial herbs with bulbs (Lily, Onion, Hyacinth), rhizomes (Solomon's Seal, Lily of the Valley), or corms (Meadow Saffron), but the order also includes a few shrubs (*Butcher's Broom*) or even trees (*Yucca, Dracaena*). The flowers are regular and hypogynous. The flower-parts outside of the stamens are all coloured, and do not differ much, if at all, in form; they are therefore said to form a *perianth*. The perianth nearly always consists of six parts, rarely of eight parts (*e.g.* Herb Paris, Aspidistra), and usually there is a division into three inner and three

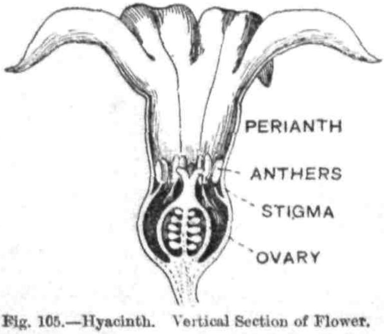

Fig. 105.—Hyacinth. Vertical Section of Flower.

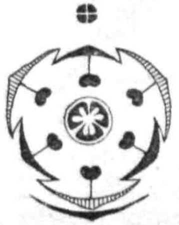

Fig. 106.—Floral Diagram of a Hyacinth.

outer parts. There are usually six stamens, arranged in two series (whorls), outer and inner. The pistil usually consists of a three-chambered ovary with numerous ovules in each chamber, a single style, and a three-lobed stigma. Note that in Wild Hyacinth and Tulip the perianth-parts are free from each other, whilst in the majority of Liliaceae (fig. 105) they are carried up as lobes on the margin of a tube, the stamens being inserted on the inner side of the tube. Both self- and cross-pollination occur, most of the flowers being adapted for long-tongued insects. In Aspidistra ("Parlour Palm"), which belongs to E. Asia, the flowers are produced close to the ground, and are pollinated by small insects which creep through openings between the four large stigma-lobes (according to some

accounts, the flowers are pollinated by snails). In most Liliaceae, honey is produced by glandular tissue in the partitions between the chambers of the ovary. In *Colchicum*,* honey is secreted on the outer side of the filaments of the stamens, at the bases of their free parts, not in the long perianth-tube. In Tulip and Garlic there is no honey, but the flowers are visited for pollen. In Herb Paris, the dusky colour and fetid smell of the flower attract carrion-loving flies, which alight on the stigma and then crawl over the anthers, becoming dusted with pollen. The Butcher's Broom has flat green branches (cladodes), and the true leaves are represented by small scales; it flowers throughout the colder months of the year, the flowers (borne on the cladodes) usually being ***dioecious*** (some with stamens only, others with pistil only). Asparagus also has small scaly leaves and needle-like green branches which carry on the functions of foliage-leaves; sometimes these cladodes are flattened. That the cladodes of Butcher's Broom and Asparagus are really branches is shown by the fact that they bear flowers, and that they arise in the axils of scales (the true leaves) on the stem.

Other plants belonging to this family, which should be examined, are: Garden Hyacinth, Lily of the Valley, Solomon's Seal, Star of Bethlehem, Liliums, Yucca, Smilax, Bog Asphodel.

252. **The Daffodil Family (Amaryllidaceae)** differs from the previous order mainly in the fact that the flowers are epigynous and the ovary inferior instead of superior. The inflorescence consists of a few flowers, or of a single one, as in the Snowdrop. In the Daffodil a series of membranous outgrowths develop on the inner surface of the perianth, just below the free lobes of the latter. These outgrowths grow together and form a tube or ***corona***, which is short in some Narcissus flowers, but in the common Daffodil attains a considerable length. In the Snowdrop and the Snowflake there is no corona, and the parts of the perianth are free.

This is a large and widely distributed order, usually occurring in dry sunny habitats. It includes many showy garden plants (Amaryllis, Crinum, Alstroemeria, Clivia, Haemanthus, etc.), also the large American Agave.

253. **The Iris Family (Iridaceae).** This order resembles the previous two in its general vegetative characters, especially as regards the existence of a perennating bulbous, tuberous, or rhizomic underground stem. The flower can be distinguished from that of a Lily by its inferior ovary, and from that of an Amaryllid by its possessing only three stamens instead of six. In some of the species of Crocus the ovary is underground; the honey secreted by the glands on it rises in the slender perianth tube nearly up to the open throat, where it is sipped by bees and butterflies. The stamens

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* Often called "Autumn Crocus," though not allied to true Crocuses.

Fig. 107.—Vertical Section of Flower of Iris. (After Church.)

On the left are shown an outer perianth segment, a petaloid style entire, and an inner posterior perianth segment cut in half. On the right an outer anterior perianth segment and a style are cut in half showing a stamen lying between them; at the back is a lateral inner perianth segment (petal); s = stigma.

dehisce before the stigma expands. Hence cross-pollination usually occurs, although if unfertilised, self-pollination may occur as the stigmas expand between the anthers. The ripened ovary is carried above ground by the elongation of the flower-stalk, and it then dehisces and scatters the seeds.

The common Iris or Flag has three petaloid styles, a stigma (*s*, fig. 107) lying in a notch on the outer face of each style. A stamen lies between each stigma and one of each of the three outer lobes of the perianth. Nectar is present at the base of the flower, secreted by the lower part of the perianth-tube; the larger outer perianth-leaves form a landing-place for the insect, which in probing for honey first touches the stigmatic surface on the lower side of the overarching style. The anther opens on its outer face, but as it lies below the stigma the insect touches the pollen after rubbing the stigma. Examine Crocus, Iris (two species occur in this country, Yellow Flag and Roast-beef Plant); Gladiolus, Ixia, Freesia, Tritonia, and others are often cultivated.

254. **The Orchid Family (Orchidaceae)** is characterised by an inferior one-chambered ovary and a zygomorphic petaloid perianth, which is frequently spurred. There is a single stamen,

which is united with the style to form the "column" in the centre of the flower (fig. 108). Very high specialisation for cross-pollination has taken place in the plants forming this order.

This order consists entirely of herbaceous perennials. Our British species are all terrestrial, and commonly have tubers in which food-materials are stored up for next season's flowering. These subterranean tubers usually consist of a swollen root with a bud attached to it, but many of the *epiphytic* Orchids which grow so commonly upon tropical trees have tubers which are stem-structures ("pseudo-bulbs") and are of necessity above ground. The epiphytic forms have aerial roots, some of which frequently hang freely downwards and are able to absorb moisture from the air, while others

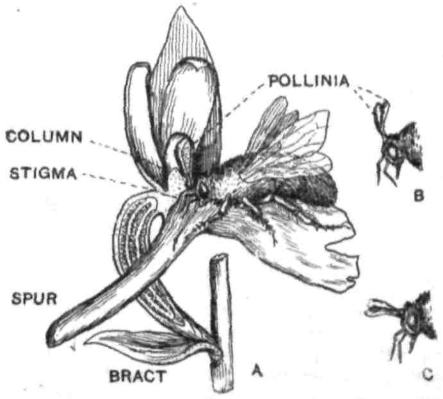

Fig. 108.—Pollination of Orchid by a Bee.
At C the pollinia have bent forward and will touch the stigma of the next flower visited.

attach the plant to its support Certain of the roots of the Vanilla plant are short and act as coiling tendrils, while others grow downwards and strike root in the soil. Many orchids, and especially the epiphytic forms, are adapted to xerophytic conditions, and hence are able to grow in dry situations. Such forms often store up water in their swollen roots or stems.

The inflorescence is a raceme, but the stalk of the flower is usually very short; the long inferior ovary makes a long flower-stalk unnecessary, as it pushes out the flower and exposes the essential parts to visiting insects. The structure of the orchid flower is rather complex, but the arrangements for cross-pollination are easy to understand if specimens of any species—*e.g.* the common Early Purple

Orchis—are carefully examined. In Orchis, the three outer perianth-lobes (sepals) are similar in size and shape, but one of the inner lobes (petals) is very different from the others. This large lobe (*labellum*) is really the posterior one, but it is brought to the front of the flower by the twisting of the ovary. It consists of a broad lip and a spur in whose wall honey is secreted. There is only one fertile stamen, which is carried up with the style so as to stand above the stigma, and it consists of two club-shaped organs, the *pollinia*. Each of these consists of a mass of pollen-grains with a stalk, and the two pollinia are joined below to a sticky gland.

Fig. 109.—Floral Diagram of an Orchid.

The latter adheres to the head or proboscis of bees in search of the nectar or succulent tissue at the bottom of the spur, and the entire pollinium is carried to another flower to whose stigma some or all of the pollen adheres. Contact with the stigma is often assured by the fact that the caudicle bends forwards and downwards as it dries while attached to the bee's head (fig. 108 B, C).

The ovules develop, and are fertilised some time after pollination. Most Orchids are cross-pollinated by insects, but some have either cleistogamous flowers, or open ones which are usually self-pollinated—*e.g.* Bee Orchid. Many, however, cannot be fertilised by their own pollen, and in a few cases the latter even acts like a poison.

There is great diversity among Orchids in the structure of the flower and the mechanism of pollination. Examine all the wild or cultivated Orchids obtainable; the commoner British Orchids are Orchis (several species),* Bee Orchid, Tway-blade, Butterfly Orchid, Bird's-nest Orchid (a saprophyte), Lady's Tresses.

Exp. 354. After examining the structure of an Orchis, *e.g.* Early Purple, push a pointed pencil into the spur of the labellum (to imitate the action of a bee thrusting in its tongue to scrape the honeyed walls of the spur). Notice the two club-shaped masses of pollen which are withdrawn from their pockets and remain attached to the pencil by the sticky mass at the base of their stalks. What change in position do the pollinia undergo after being removed, and how does this help in bringing about cross-pollination?

255. **The Grass Family (Graminaceae).** These are usually herbs, or, if tree-like, as in the case of the Giant Bamboos, without any secondary increase in thickness. The stem is cylindrical, with solid "nodes" and hollow "internodes," but is solid throughout in the Maize. The leaves are usually alternate and in two opposite rows, the lower ones being often crowded and forming a basal tuft. Each leaf has a sheath which forms a tube around the stem, the two edges

* The commonest British species of *Orchis* are the Early Purple, Spotted, Marsh, and Fragrant Orchids.

usually overlapping on the side opposite the blade, and the latter is usually long and narrow. The sheath is prolonged above its union with the blade to form the ligule, which is generally papery, but may be represented by a row of hairs or may even be absent.

The inflorescence is composed of a series of "spikelets" grouped together in the form of a spike, as in the Wheat and perennial Rye grass, of a loose panicle, as in the Oat, or in a dense cylindrical panicle, as in the Fox-tail grass and the Timothy grass.

Each "spikelet" consists of a slender axis bearing a double row of closely set scales. The two lowest scales or *glumes* are barren—that is to say, they have no flowers in their axils (fig. 110). The scales or

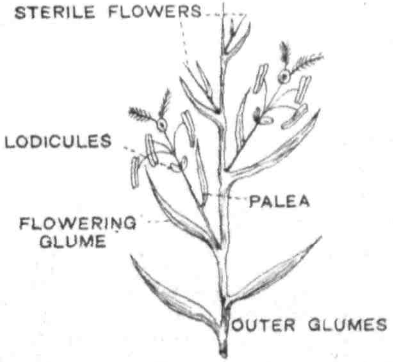

Fig. 110.—Diagram of a Grass Spikelet.

bracts above these are differently shaped, and are termed the flowering glumes, and each of these has a flower in its axil. Lying opposite to the flowering glume, between it and the stem, and arising from the stalk of the flower, is a second thin scaly and two-ribbed bract, termed the *palea*. When the spikelet contains a number of flowers, the third glume, or lowest flowering glume, is usually close to the second; its flower is often imperfect, or it may even be sterile and intermediate in shape between the lower sterile glumes and the upper flowering ones.

Each flower lies between the outer bract (flowering glume) associated with it, and the inner palea. It consists of a pair of minute scales or *lodicules*, three (rarely two or six) stamens and an ovary crowned with a couple of feathery stigmas (figs. 110–2). The two lodicules are supposed to correspond to a perianth. At the time of flowering they swell and push apart the glumes, so that the anthers and stigmas are exposed. After pollination the lodicules

shrivel and the glumes close over the developing fruit. In some cases the lodicules are minute (Fox-tail grass) or absent (Timothy grass). Here the stamens and brush-like stigma are never so freely exposed. Each spikelet may contain from one to six or even more flowers, and frequently the terminal flower of the spikelet is rudimentary, or the apex is occupied by an empty glume. Occasionally one flower, either above or below the perfect ones, has stamens only, and some foreign species, *e.g.* Maize, always have unisexual flowers. The male and female flowers of the Maize are grouped in separate inflorescences on the same plant.

Fig. 111.—Flower of Wheat enclosed in its two Scaly Bracts or Glumes.

Frequently the midrib of the flowering glumes alone, or only of the intermediate empty ones, or of all the glumes, is prolonged into a bristle, or awn (fig. 112), which sometimes attains a length of several inches (Barley, etc.). The awn is either terminal, or is inserted on the back or at the base of the glume. Awns not only appear to act as a protection against browsing animals, but frequently favour dispersal, and also seem

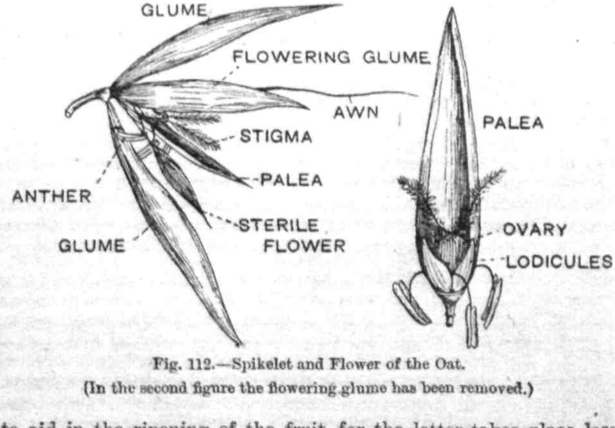

Fig. 112.—Spikelet and Flower of the Oat.
(In the second figure the flowering glume has been removed.)

to aid in the ripening of the fruit, for the latter takes place less perfectly and more slowly when they are removed. The awn

corresponds to the reduced leaf-lamina, the basal portion of the glume to the leaf-sheath, and the free portion beyond the base of the awn to the ligule.

The pistil corresponds to three fused carpels forming a unilocular ovary with a single ovule. This is readily seen in the ovary of the Bamboo. *Most grasses have but two styles and stigmas however*, and in Maize the reduction has proceeded still further, only a single stigma being present.

The pollen is carried by the wind, and hence is abundant, dry, and powdery, and easily escapes from the hanging anthers. Each stamen has a long filament, which is attached to the middle of the anther, so that the anther swings about in the lightest breeze. The feathery stigma exposes a large surface for the reception of pollen. In such plants as the Maize only cross-pollination can occur, but our native cereals are usually self-pollinated, and in some cultivated varieties of Barley the flowers never open.

256. **Monocotyledons and Dicotyledons.** The Liliaceae, Amaryllidaceae, Iridaceae, Orchidaceae, and Graminaceae belong to the group of Monocotyledons; the orders previously dealt with in this chapter are Dicotyledons. These are the two classes into which the higher flowering plants, those in which the ovules are developed in a closed ovary, are divided. The two groups are well defined, though they have many features in common, and most of the characters used to distinguish them break down in some cases. The chief differences between them occur in the structure of the stem, the arrangement of the leaf-veins, the number of parts in each series (whorl) of flower-leaves, and the number of cotyledons in the embryo. From your work on plants, and from the details given in this and in previous chapters, you should draw up in parallel columns a comparison between the two groups, giving the contrasting characters as regards (1) embryo, (2) growth of seedling, (3) structure of stem, (4) structure of root, (5) presence or absence of secondary thickening in stem and root, (6) venation of leaf, (7) arrangement of flower-parts. Also note any exceptions to some of the distinctions which you have observed. For example, some Monocotyledons have net-veined leaves (*e.g.* Arum, Black Bryony), some have the flower-parts in fours, etc., and on the other hand some Dicotyledons (*e.g.* Barberry) have the flower parts in threes.

257. **Inflorescences.** Flowers may either be solitary or may occur in clusters. In the latter case they are usually subtended by special leaves termed bracts. Solitary flowers may be either terminal, as in the Tulip or Daffodil, or may arise in the axils of ordinary leaves, as in the Ivy Veronica and Money-wort. Such flowers may be regarded as reduced inflorescences, in which the main axis remains unbranched, and only one flower develops. The branching of an inflorescence follows fundamentally the same laws as that of the stem, and may be either cymose or racemose. In racemose inflorescences the main axis is stouter and longer than the lateral ones, whereas in the cymose type the lateral axes branch more than does the main axis beyond them. The growth of the main axis is in this case strictly limited, and it bears usually one or two primary lateral axes, instead of the numerous ones which characterise most racemes. The order of flowering usually follows the order of development, and hence the flowering in racemes is generally centripetal, whereas that of cymes is on the whole centrifugal.

258. **Racemose Inflorescences.*** The simplest type of raceme consists of an elongated axis or peduncle which bears stalked flowers (fig. 87). Examples of such racemes are exhibited by the Lily of the Valley, Foxglove, Hyacinth, Currant. If the branches of the parent axis branch again so that each secondary axis bears several blossoms instead of one, we have what is known as the compound raceme or **panicle.** This is the most primitive type of inflorescence, for it is really the modified upper region of the plant, whereas the simple raceme is more highly differentiated and has become simple by reduction.

259. **Biological Improvements on the Typical Raceme.** Many terms have been applied in the past to inflorescences which look peculiar at first sight, but on further observation are seen to differ in small details only. The more important of these are (1) corymb, (2) spike, (3) spadix, (4) catkin, (5) umbel, (6) capitulum.

(1) For example, it sometimes happens that the lower branches of a raceme are as long as, or longer than, the portion of the central

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* Highly instructive models can be made out of bits of cork, pointed strips of stiff paper gummed at the broad end (bracts), and matches pointed at their lower ends, the head of each match representing a flower.

axis which bears them, so that the flowers all lie at about the same level. This type of inflorescence is known as the **corymb** (fig. 88), and usually the lengthening of the lower branches is accompanied by a shortening of the main axis, due to the retarded development of the upper internodes. Good instance are exhibited by many Cruciferae (viz. Candytuft). The raceme of the Wallflower is corymbose when young, but lengthens out when fruiting. (2) The **spike** (fig. 113) is a simple raceme in which the flowers are sessile, as in the Plantain (*Plantago*), or very nearly so, as in *Verbena*. (3) The **spadix** is similar to a spike, except that the axis is stout and fleshy, while the flowers are small, unisexual (staminate or carpellary), and closely packed together. The spadix is more or less closely invested by a large leaf-like expansion known as the spathe, which is green in the common Arum (fig. 130), but brightly coloured in the hot-house plant known as *Anthurium*. In the latter case the entire spadix bears flowers, there being no sterile terminal portion as in *Arum*. (4) The **catkin** is a more or less pendulous spike of unisexual flowers, which falls as a whole when flowering is over. It is found in many nut-bearing trees (Birch, Oak, Hazel) and in others as well (Poplar, Willow). (5) The **umbel** is to be regarded as a modified raceme of stalked flowers, in which the main axis has become so much shortened that the flowers all arise at the same level (fig. 93). It is in fact easy to see how the umbel could be derived from a corymbose raceme by a process of shortening and compression. In the simple umbel each of the secondary axes bears a flower, but usually umbels are compound, each secondary axis bearing a little umbel of stalked flowers, with or without a series (*involucel*) of small bracts (fig. 94). Since the umbel is a modified raceme, the first flowers to open are the outer ones. The order of flowering follows a spiral line leading from without inwards in each umbel, and frequently ends with a central terminal flower, as is also the case in many racemes whose growth is strictly limited. Many umbels, however, have become so highly specialised that the flowers open almost simultaneously. The Ivy and Cherry afford examples of simple umbels, the Parsnip, Carrot, Fennel, Parsley, and Pignut of compound ones. (6) The **capitulum** (fig. 102) is a racemose inflorescence of sessile flowers crowded together on a short, broad, parent axis. The capitulum may be regarded as a modified spike which has become shortened and condensed. The disc, or receptacle from which the flowers arise, may be concave or flat, but is usually convex. Examples of capitulums are afforded by the Compositae and by the Sheeps-bit (*Jasione montana*). The heads of the Daisy, Dandelion, or Marigold are not single flowers, but inflorescences of

Fig. 113.—The Spike (Diagrammatic).

small sessile ones. The green or scaly and usually overlapping leaves, which form an involucre or investment around the capitulum, are simply reduced leaf-members. True bracts are present in the head of the Sunflower, for each flower in the capitulum arises in the axil of a scaly leaf, as can easily be seen when the latter is still young. In other Compositae the bracts between the flowers are much reduced, and in the Daisy, Dandelion, and Thistle no trace of them remains. Owing to the close aggregation of the flowers in the inflorescences of these plants, large bracts would be an obvious disadvantage, and since the young flower buds are not exposed, small bracts are unnecessary. When present, the theoretical importance of these bracts is considerable, for in themselves they suffice to show that each of the little florets, as they are called, is really a sessile flower, which has become somewhat reduced and simplified.

260. **Cymose Inflorescences.** In these the main axis terminates in a flower, and lateral axes continue the growth of the inflorescence. When a single secondary axis occurs at each branching, the cyme is said to be uniparous; when two are present, it is biparous; when more than two, it is multiparous. Some of the most highly specialised types of uniparous cyme develop as if they were dorsiventral structures, and the resulting unilateral inflorescence is the so-called "helicoid" cyme (fig. 114). A few racemose inflorescences, however, exhibit the same peculiarity (Vetches, Foxglove, etc.). Biparous cymes or dichasia occur among plants belonging to the natural order Caryophyllaceae (Pinks, Campions, etc.) In these plants the successive pairs of daughter-axes usually develop to the same extent, but more frequently this is not the case, and a form of inflorescence is then produced which exhibits several points of similarity to a raceme. In such cases as these it is by no means always easy to determine precisely to what category a particular inflorescence belongs. Thus the Buttercup has a reduced panicle, which needs but little further change to become distinctly cymose. Again, in the multiparous cyme of Spurges, the parent axis terminates in a flower, and beneath that gives rise to three or more whorls of daughter-axes terminated by flowers. This is not unlike a shortened raceme in which the development of a terminal flower has been hastened, and the vegetative activity of the main axis retarded.

Fig. 114.—Inflorescence of *Myosotis* (Scorpion-grass, Forget-me-not).

261. **Comparison of Cymose and Racemose Types.** In any case it seems probable that all cymose inflorescences have been derived from racemose ones by a shortening of the main axis and a delay in the development of the lateral branches, to which the main power of growth is at the same time transferred. The cymose inflorescence is certainly an advance upon the racemose type, for in the former new flowers continually appear on the exposed surface of the inflorescence, while the fruits ripen securely buried among the older parts of the mass of branches. The tendency in racemes, on the other hand, is to simultaneous flowering, such as is exhibited more or less perfectly by so many umbels and capitula and especially by corymbs. In such cases there is an ever-present danger that the short period of flowering may occur at a time when the conditions are not suitable for the production of fertile seed. Racemes such as those of the Wallflower, in which the lower flowers may open months before the apex of the raceme ceases flowering, do not incur this danger, but the exposed position of the young succulent fruits is an obvious disadvantage here and in other Crucifers also. Moreover, if the growing point of a young raceme is destroyed, the power of producing flowers may be temporarily lost, whereas the destruction of the apex of a cyme involves the loss of a single flower only, and the lateral axes continue their growth with even greater vigour than before.

262. **Special Forms of Inflorescences.** In many cases mixed inflorescences occur—as, for example, racemes of spikes, capitulums, or cymes, spikes of capitulums, etc. It must, however, be borne in mind that there are only three main types of inflorescence, and these are (1) the raceme, with its reduction derivatives grouped around the generalised panicle type; (2) the biparous cyme; (3) the uniparous cyme. "Mixed" inflorescences arise owing to the fact that reduction or alteration has unequally affected the different parts of the primitive panicled inflorescence. The inflorescence of the garden Geranium (*Pelargonium*) and of many Narcissi resembles an umbel, but the flowers in the apparent umbel are really arranged in little cymose clusters, so that the whole inflorescence has been termed an umbellate cymose head. The Sweet-William has a dense, copiously branched biparous cyme, in which the axes are short and the flowers crowded together. In all such cases it is sufficient to speak of the inflorescence as **aggregated,** without employing any special term ("fascicle").

A peculiar aggregation type occurs in the Dead-nettle (figs. 96, 97) and other Labiates. The clusters of flowers occurring at the nodes in the axils of each of the pairs of upper leaves are really biparous cymes, which become uniparous after the first branching. This is difficult to recognise owing to the fact that the flowers have almost lost their pedicles and have become practically sessile, but it can be made out in those Labiatae in which the flowers still possess short but distinct stalks (Calamint), especially if these arise in the

axils of bracts, as in the Horehound (*Ballota*). In fig. 97 a single cluster of flowers is diagrammatically represented. The main axis (1) terminates in a flower and gives rise to two lateral axes (2), each of which terminates in a flower, and gives rise to a single axis (3).

The apparent flowers of the Spurge (*Euphorbia*) are really inflorescences, which are sometimes termed cyathiums (fig. 115). Each is surrounded by a cup-shaped involucre formed by the union of five bracts. Four crescentic glandular scales occur at the margin of the involucre between four of the bracts. Inside the cup there appear to be a number of stamens and a single ovary borne on a stalk. The latter is really a carpellary flower, and each of the former corresponds to a single staminate flower, as is indicated by the fact that each stamen is articulated to a short stalk, and that at this point a small scaly bract occurs. In some allied plants a small perianth is present at the base of every stamen, which clearly shows that each of them corresponds to a single reduced flower.

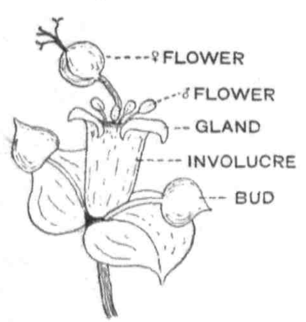

Fig. 115.—Inflorescence of Euphorbia.

The occurrence of bracts, and the positions which they occupy, are features of great importance in determining the nature of compound or mixed inflorescences. Bracts are usually green, and smaller and simpler than the foliage leaves. In some Sages they are brightly coloured, and take on the attractive function of a corolla. They are absent from most Cruciferae and Papilionaceae, and the flowers (florets) of most Umbelliferae and Compositae are bractless. Sometimes a series of specially modified leaves which do not subtend flowers, and which therefore are, strictly speaking, not bracts at all, are grouped around the inflorescence. Thus the head of the Daisy or Dandelion has a ring or *involucre* of green "bracts" around it, although the individual flowers have none. In the head of the Sunflower, however, each flower arises in the axil of a true scaly bract. Sometimes, as in Narcissus, Arums, and Palms, the entire inflorescence is enclosed when young by a single large "bract" or spathe. The latter, however, is simply the uppermost leaf on the stem, and it is not a true bract at all, for the inflorescence is terminal and not axillary.

The student will usually have little trouble in making out the nature of any inflorescence if the foregoing paragraphs have been mastered. Specimens of all the plants mentioned should be examined carefully.

263. **The Parts of the Flower.** The outer floral parts, exclusive of the stamens and carpels, constitute the perianth, which may either be single or, more commonly, double. If the outer series of parts in a double perianth are distinctly differentiated from the inner, we term the former the calyx of green sepals, and the latter the corolla of coloured petals. Not unfrequently, although two series or whorls of parts are present, they are inserted so closely together upon the thalamus that they fuse to form a single investing envelope. In such cases the latter is frequently described as a perianth, since it is hardly possible to distinguish between the sepaline and petaline parts (*e.g. Narcissus*). Many flowers, however, have a perianth which is composed of a single ring or series of parts only, while some flowers are naked and have no perianth at all.

The perianth forms the non-essential part of the flower, whereas the stamens and carpels are the essential organs, and one or both of these must be present to constitute a flower. A typical flower possesses sepals, petals, stamens, and carpels arranged in single or double alternating rings, each ring containing the same number of similar parts. In comparison with such a flower, when any of these parts are absent we say the flower is incomplete. Flowers which have no carpels are said to be male * or staminate, those without stamens are female * or carpellary (pistillate). In some flowers, as in those of the Daisy and other Compositae, it can be seen by comparison with allied types that the calyx is aborted; in such flowers the outer ring of parts must be described as the corolla and not as the perianth. Similarly in Anemone, Clematis, and Marsh Marigold, it is usually stated that the corolla is wanting, and the calyx becomes petaloid. There is, however, no sure evidence of the abortion of the petals, or of their conversion into stamens, so that it is possible that in these plants, as well as in the Nettle, Oak, Hazel, etc., the presence of a single series of perianth parts may be a primitive ancestral character.

* These terms are incorrect in this connection, but are permissible in a physiological sense, as denoting function.

264. **Calyx.** The calyx has usually a protective function, and primitively it consists of a spiral of separate *sepals*, which have no stalks, but arise directly from the thalamus, as small green sessile leaves. The individual sepals may be free or polysepalous, as in the Geranium or Wallflower, but when they are united to however slight an extent, the calyx is gamosepalous, as in the Primrose or Dead-nettle. However complete the union may be, the number of sepals which take part in the formation of the calyx is usually indicated by the pointed teeth borne on the upper margin of the tube. In the Monkshood the petals are very much reduced, and one of the sepals form a coloured arching hood placed at the back of the flower. When a calyx is present, it is usually composed of two, three, four, or five sepals. Thus the Poppy has a single pair, the Lesser Celandine a whorl of three, the Violet one of five sepals, while the Wallflower has four sepals in pairs, forming an inner and an outer whorl of two. More rarely the outer parts of the perianth are numerous, and retain their primitive spiral arrangement (Water-lilies, Cactuses).

The calyx commonly serves to protect the flower while it is still young, and hence, when the flower opens, the sepals either fall off (Poppy) or turn back (Dog Rose). Another of its functions, however, is to protect the developing fruit, and hence it often persists until the fruit is formed, as in the Bean, Strawberry, and Dead-nettle. A gamosepalous calyx affords not only a more efficient protection to the flower-bud than a polysepalous one, but also gives support and protection to the base of the adult flower, and also to the developing fruit. Hence the gamosepalous calyx never falls off when the flower is young—*i.e.* it is never *caducous*, as it is in the Poppy. When the flowers and fruits are closely aggregated, they no longer need a protective calyx, which therefore becomes quite small, as in Umbellifers, and when a closely packed mass of flowers is surrounded by a ring of protective bracts, the calyx may either disappear (Daisy) or be represented only by a few fine hairs. These hairs in the Thistle, Hawkweed, etc., persist after flowering, and form a silk pappus, which is attached to the ripened fruit, and aids in its dispersal by the wind.

The sepals are usually green, but the "petaloid" sepals of the Larkspur and the perianth parts of the Marsh Marigold are brightly coloured, and usurp the attractive function of the corolla. In the Wallflower the two outer sepals are slightly pouched at their bases, so that they may retain the nectar secreted by the glandular swellings placed beneath the bases of each of the two shorter stamens.

265. The primitive **Corolla** consists of a spiral of free non-coherent petals. In most plants this has been changed into a single whorl (Foxglove, Geranium) or, more rarely, a double whorl of petals (Poppy). In Water-lilies and in double flowers, the petals are arranged in a close spiral. The corolla protects the stamens and carpels at the most critical period of their existence, and this is

especially the case when the petals are united together in the form of a tube enclosing the essential organs. The tube of the corolla also serves as a receptacle for honey, while the coloured portion attracts the visits of insects. As soon as fertilisation has occurred, the seeds begin to develop, and an attractive corolla being no longer needed, it is usually rapidly shed. The withered corolla may, however, persist in a few cases (Gooseberry, Currant).

When the corolla is polypetalous, the individual petals often consist of a long, narrow stalk or claw, and an upper broader portion, the blade or limb. The petals of the Pink have a scaly outgrowth (ligule) at the junction of the claw and limb, and in Narcissus these outgrowths unite to form a circular cup, or *corona*, around the throat of the corolla.

The corolla is said to be regular (actinomorphic) when all its parts are similar, irregular when they differ in shape from one another, and the same terms apply whether it is poly- or gamopetalous. The term corolla is not applied when there is only a single ring of perianth parts, even when these are coloured, as in Clematis and Anemone. In the Christmas-rose, the petals are represented by hollow tubular nectaries, and the sepals form the showy attractive portion of the flower. The nectaries might be modified stamens, in which case the outer ring of parts would be simply an undifferentiated single perianth. The nectaries are, however, represented in the Buttercup by tiny pockets placed behind a scale at the base of the inner surface of each petal, and nectaries do not seem to arise on the stamens in flowers belonging to this order. Hence the nectaries of the Christmas-rose are probably modified petals, as are undoubtedly the two posterior ones of the Monkshood.

266. The **Andrecium** is the collective term applied to the whole of the stamens present in any single flower. Each stamen usually consists of two parts, a stalk or filament, and a head or anther. There may be no filament, so that the anther is sessile, or the anther may not develop, when what remains is known as a *staminode* or sterile stamen. The anther is usually divided into two halves or lobes, in each of which are a couple of longitudinal compartments, filled, when ripe, with pollen grains. When the anther splits open, or dehisces, the partition between the paired pollen sacs of each lobe breaks down to a greater or less extent, so that frequently each lobe appears to have only a single cavity. This fusion sometimes occurs at a comparatively early stage in the development of the anther. In a few cases the stamen undergoes segmentation into two when quite young, so that each piece has only two pollen sacs (Hazel, Hornbeam).

The prolongation of the filament between the two lobes of the anther is termed the *connective*. When the lobes are close together, this is narrow; but in Labiates and other plants the connective is elongated laterally, and the anther lobes are widely separated. Special appendages are occasionally developed from the connective.

Thus each anther of the Violet has a membranous orange-coloured outgrowth at its apex, and in addition each of the two anterior stamens has an elongated process extending downwards into the spur on the anterior petal. The tip of this process is glandular, and secretes nectar into the spur.

As a general rule the different stamens of a flower are alike in shape, size, and in length of filament. Two of the stamens of the Wallflower, however, are shorter than the other four (tetradynamous), while the Dead-nettle has two long and two short stamens (didynamous). In certain Geraniaceae (*Erodium*, *Geranium pusillum*) five of the stamens possess anthers, and five are usually without them (= *staminodes*), while the Garden Geranium has three staminodes and seven fertile stamens.

The fully grown anther dehisces and allows the pollen to escape. It usually happens that the wall of each lobe splits longitudinally along the dividing line between its two compartments, but among many Labiates the anther dehisces transversely. In the case of the Potato, Rhododendron, and Milkwort, small pores are formed at the top of the anther. In the Barberry the whole side of each anther-lobe bends upwards; in the Laurel small doors or valves open at the sides of the anther.

267. The **Gynecium** or **Pistil** is the collective term applied to the carpels present in a flower. In its simplest form the pistil consists

Fig. 116. — Carpellary Leaf with Marginal Ovules.

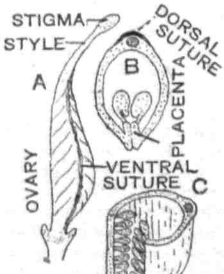

Fig. 117.—The Monocarpellary Pistil.

A, Entire; B, Transverse section of ovary; C, Will indicate method of folding.

of a single carpel, as in the Bean. Such a carpel corresponds to a leaf bearing ovules on its margins (fig. 116), a condition in which the carpels of the Gymnospermous plant *Cycas* remain to the

present day. We might suppose that as the higher flowering plants developed, the two halves of the carpellary leaf folded together longitudinally, and that ultimately their margins became coherent along a line known as the ventral suture, which bears a double row of ovules derived from the two margins of the leaf. The purpose of this change is immediately obvious, for the young ovules are now protected within a hollow chamber known as the *ovary* (fig. 117), which is formed from the swollen basal portion of the carpel. The apical portion of the latter forms a slender prolongation of greater or less length, the *style*, which usually contains a central canal communicating with the cavity of the ovary, but may be composed of loose, solid tissue with no definite central cavity. The *stigma*, or apical portion of the style, is usually swollen and covered with hairs (stigmatic papillae). The stigma forms the receptive surface for the pollen. The dorsal suture of the carpel corresponds to the midrib of a leaf; the cushion of tissue along the ventral suture, from which the ovules arise, is known as the placenta.*

The flower of Buttercup or Rose contains several free simple carpels, and the pistil is therefore termed *apocarpous*. When several carpels are present in a flower, they are often united to form a compound or *syncarpous* pistil. The union may be confined to the base of the

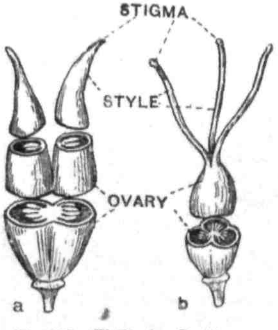

Fig. 118.—Pistil of *a*, Saxifrage; *b*, St. John's Wort.

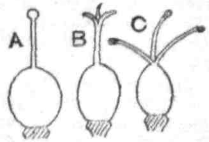

Fig. 119.—The Syncarpous Pistil.

ovary (*Saxifraga*, fig. 118 a), or may include the entire ovary (*Hypericum*, fig. 118b), or only the stigmas may be free, as in the Foxglove, or all three may be completely united together, as in Primroses. A syncarpous ovary may be divided into a number of

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* In the Water-lily, Flowering Rush, and a few other plants, the ovules are scattered all over the inner surface of the carpels.

compartments or loculi, each loculus corresponding to the cavity of one carpel. Thus the Tulip has a tricarpellary gynecium, and the ovary is divided into three compartments, each containing a double row of ovules. The ovary of the Violet has a single chamber only, although it is composed of three carpels, as is indicated by the presence of three groups of ovules arranged in longitudinal rows

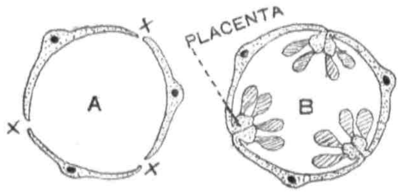

Fig. 120.—Formation of Unilocular Ovary from three Carpellary Leaves by Fusion at X.

upon its wall. When, as in this case, the ovules are attached to the wall of a compound ovary, the placentation, or arrangement of the placentas, is said to be *parietal* (figs. 120, 121); but when the ovules arise from the longitudinal axis in the centre of the ovary, the placentation is said to be *axile* (fig. 122 B). It will be noticed that when the placentation is axile, the ovules in each loculus are

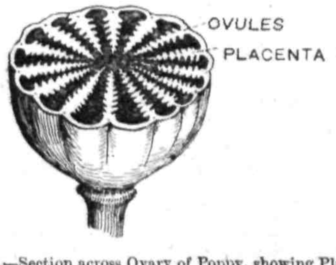

Fig. 121.—Section across Ovary of Poppy, showing Placentas bearing the Ovules.

derived from the margins of the carpellary leaf that forms this compartment, whereas in the case of parietal placentation each group of ovules is derived from the margins of two adjacent carpellary leaves, half from each. In the Chickweed, Stitchwort, Sandwort, etc., the central axis of the ovary does not reach the roof of the latter, so that the ovules appear to arise from a mound in the centre

of the ovary (fig. 123). This type of placentation is said to be *central*, and it is really a modified form of axile placentation, in which the dividing septa do not develop, although this is probably

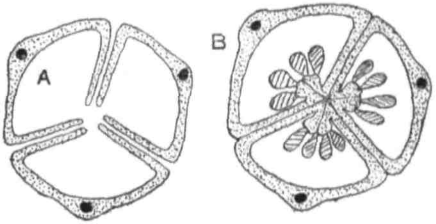

Fig. 122.—Formation of Trilocular Ovary, B; from three Carpellary Leaves, A.

not a primitive condition, but a secondary adaptation, the attachment being such that the ovule is more readily provided with nutriment.

The only safe way of determining the number of carpels in a syncarpous gynecium is by studying its development, and noting how many leaf-rudiments fuse to form it. Adult flowers, however, often afford evidence of value to beginners. Thus the number of chambers in an ovary usually corresponds, if there are more than one, to the number of carpels of which it is composed. In Labiates and Borages, however, each compartment of the bicarpellary gynecium is divided into two, so that there are four loculi, but only two carpels. The ripe ovary of the Flax becomes similarly divided into ten chambers instead of the five present at first. Again, in unilocular ovaries with parietal placentation, each placenta usually corresponds to a single carpel, although in the case of the Water-lily the inner surfaces of the carpellary compartments of the ovary are studded with ovules. The number of styles or stigmas often corresponds to the number of component carpels, and the ripe fruit frequently splits into as many pieces as there are carpels, although the pieces do not necessarily precisely correspond to them. In White Water-lily the numerous petals pass by gradual transitions into the more centrally placed stamens, all being spirally arranged on the receptacle; in double Roses the stamens, in double Buttercups both stamens and carpels, become petal-like; in White Clover the carpel sometimes remains open and produces green leaves on its edges; in green Roses, double Cherry, etc., the carpels grow into green leaves.

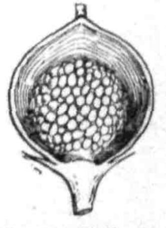

Fig. 123.—Unilocular Ovary with Free Central Placentation.

268. **Cohesion and Adhesion.** "*Fusion*" between the parts of the same or of different whorls is of common occurrence. When the parts of the same whorl are united, they are said to be *coherent*, but when union occurs between the parts of different whorls, the term *adherent* is employed. Cohesion between the sepals, between petals, between stamens, and between carpels is of very common occurrence, although there is no flower in which all the floral whorls are coherent at the same time, if we except those Composites which possess no calyx. Adhesion is not quite so common, but it is very often the case that when the petals cohere to form a corolla tube, the lower portions of the filaments of the anthers are adherent to it, so that the stamens appear to arise from the corolla instead of from the thalamus. Adhesion between the andrecium and gynecium occurs in Orchids and in *Aristolochia*, but is otherwise uncommon. In many cases the apparent fusion appears to be the result of the formation of a ring-like outgrowth from the thalamus, carrying the free parts upwards so that they seem to have a common basis. The so-called calyx tube of the Rose arises in this way, and possibly also epipetalous stamens, and even the gamopetalous corolla and the gamosepalous calyx.

269. **Symmetry of the Flower.** Whenever a flower can be divided into two corresponding halves along a vertical plane, it is said to be symmetrical (Violet, Iris). When it can be so divided along one plane only it is said to be bilaterally symmetrical or *zygomorphic*, but when the flower may be equally divided in several vertical planes it is radially symmetrical or *actinomorphic*. In regarding flowers from the biological point of view, we may restrict these terms to the perianth. A flower that can be visited from any side has a radially symmetrical ("regular") mechanism, whereas that of a flower which can be properly visited from one side only is zygomorphic ("irregular").

270. **The Floral Diagram.** The general structure of a flower and the arrangement of its parts may be graphically represented by means of drawings of vertical and horizontal sections. The latter are always drawn as a ground plan

showing all the parts in the same figure, and the term "floral diagram" is applied to them. It is always of great importance in such diagrams to correctly represent the position of the flower with regard to the stem and bract connected with it. The face of the flower turned towards the stem is called the posterior face, that towards the bract is the anterior one. Cohesion of parts may be indicated by connecting lines. Difficulty is often experienced in correctly orienting the flower with regard to the stem, and it is useful *to remember* that there is a *single posterior* sepal in most Dicotyledons, if we except the Leguminosae and also a few plants in which the posterior sepal has not developed. The parts of the typical Monocotyledonous flower are arranged in regular cycles of three, and the odd sepal is usually anterior. Make the diagram of good size (at least 2 in. in diameter). To get a transverse section of a small ovary, do *not* remove the sepals, etc., but cut right across the flower, holding the flower upside-down, and cutting thin slices (beginning at the base of the flower) until the interior of the ovary is exposed. To cut a flower longitudinally through the middle, it is usually best to begin the cut at the base of the flower.

271. **The Floral Formula.** As a means of readily and rapidly indicating the essential features in the structure of a flower, what are known as floral formulae are frequently employed, and these, together with the diagram and longitudinal section, will represent all the essential features in the *morphological* structure of the flower without a word of description being necessary.

The symbols ⊕ and † respectively denote radially and bilaterally symmetrical (zygomorphic) flowers, the direction of the arrow indicating the plane of symmetry along which the flower can be divided into equal halves. The signs ♂, ♀, ☿ respectively denote staminate, carpellary, and hermaphrodite ("perfect") flowers. The letters K, C, or P represent the calyx and corolla (or perianth), A and G the andrecium (stamens) and gynecium (pistil), and the figure following each letter gives the number of parts in each series. Cohesion is indicated by brackets enclosing the

number of parts; a horizontal bracket ⌒ indicates adhesion between the parts of successive whorls; a horizontal line above G means that the ovary is inferior, a line below G that it is superior; the symbol ∞ is used when there are numerous parts in any series. The following floral formulas will serve as illustrations:

Buttercup . . .	☿	⊕	K5, C5, A ∞, *G* ∞.
Violet . . .	☿	†	K5, C5, A5, *G*(3).
Dead-nettle .	☿	†	K(5), $\widehat{C(5), A}$2 + 2, *G*(2).

For other examples, see Appendix III.

272. **Perigyny and Epigyny**. The shape of the receptacle or thalamus varies very much in different flowers. The thalamus of the Buttercup is convex, and the successive cycles of floral parts are placed upon it, one above the other, the sepals arising first and the carpels last. Flowers of this type are said to be *hypogynous*, and the carpels *superior*. In such flowers, the young and succulent ovaries are exposed to various climatic influences, including strong winds, intense sunlight, and rapid changes of temperature, any of which may act injuriously upon the development of the ovules, if the carpels are thin and freely exposed. There is a tendency in all flowering plants to protect the ovary from the influences mentioned above, and this tendency finds expression in three distinct ways. Firstly, the petals tend to unite as also do the sepals, thus producing flowers of very specialised character, in which the ovary is, at the same time, protected to a certain extent from injurious external influences. The second modification involves a change in the shape of the receptacle, which becomes more or less concave, and so encloses and protects the carpel or carpels, leaving the stigma exposed at the end of an elongated style. Such flowers are said to be *perigynous*, but in many cases only the marginal portion of the receptacle is concave or flattened, so that the sepals and petals seem to have a common origin, while the carpels arise from a prominence in the centre of the flower (*e.g.* Blackberry). In perigynous flowers the gynecium is attached to the receptacle by its base only, and it is still

said to be superior even when the entire receptacle is concave and only the stigmas project above it.

The third mode of protecting the ovary is somewhat different. In this case the receptacle swells, and the ovary sinks into it so as to be completely imbedded, the style

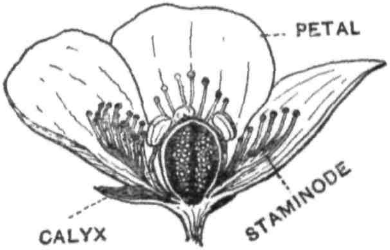

Fig. 124.—Vertical Section of Flower of *Parnassia palustris*

and stigma remaining free and projecting upwards. Here the ovary is said to be inferior and the flower *epigynous*. The wall of an inferior ovary is composed partly of the carpels and partly of the receptacle, so that not only is the ovary protected, but also an increased surface is offered through which nourishment can pass from the receptacle to the developing ovules. Many flowers with gamopetalous corollas have also inferior ovaries, the gamopetalous condition of the corolla usually indicating in such cases that the flower is highly specialised

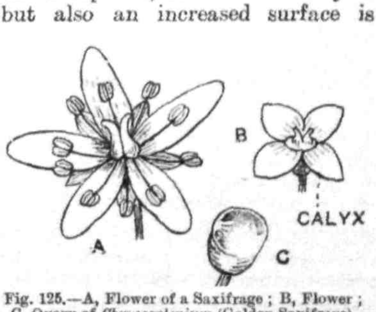

Fig. 125.—A, Flower of a Saxifrage; B, Flower; C, Ovary of *Chrysosplenium* (Golden Saxifrage).

and adapted for the visits of such insects as bees, moths, etc. The origin of epigyny is well shown among Saxifrages, for the ovary of the Grass of Parnassus (fig. 124) is almost entirely free, that of the Meadow Saxifrage is sunk half

way in the thalamus, while that of the Golden Saxifrage (fig. 125) is purely epigynous. Even here the inner side wall of the ovary simply represents the base or broad attachment of the two carpels fused in this case to form a unilocular ovary.

273. **Nectaries.** The receptacle frequently bears a fleshy or glandular outgrowth, such as is found on the top of the inferior ovary in Umbelliferae and in the common Ivy. This is termed the disc. In the Blackberry the disc lines the outer concave part of the receptacle. Very commonly the disc is lobed (Vine, Wallflower), and frequently it secretes nectar. Nectaries may, however, develop from, or upon, any part of the flower. Thus in the Violet the appendices borne by two of the stamens secrete nectar into a hollow spur borne by the anterior petal. In the Buttercup a small projection at the base of each of the petals performs the same function, while the whole of the petals of the Christmas Rose are modified into hollow tubular nectaries. Honey glands occur upon the gynecium of Gentians, and each sepal of the Hollyhock flower bears a nectary on its inner surface.

274. **Insects that visit Flowers.** The chief flower-visiting insects are beetles, flies (Diptera), bees, wasps, butterflies, and moths. For our purposes, the chief differences between these insects are the size of the body, the length of the tongue or proboscis, the time of year at which each kind is most plentiful, and their habits—*e.g.* whether they collect pollen (to feed their young) or honey or both, whether they fly by day or in the evening. By carefully studying the structure of a flower, and noting such points as the time of flowering, the order in which the anthers and stigmas mature, the relative positions of anthers and stigmas in the open flower and any changes in position that may occur, we can often tell what kind of insect is capable of effecting cross-pollination, and whether or not self-pollination is possible. We shall deal later with the characters of flowers which are mainly or entirely pollinated by the wind, and which lack the conspicuous colouring, scent, and nectar, which are characteristic of insect-pollinated flowers (though not necessarily *all* present in the same flower).

275. **Flowers adapted for Short-tongued Insects.** Most flies and beetles have very short tongues, usually less than 3 mm. long (about one-eighth inch), and are only able to lick honey which is freely exposed on the surface, as in Ivy, Umbellifers, Dogwood (*Cornus*), Golden Saxifrage (fig.

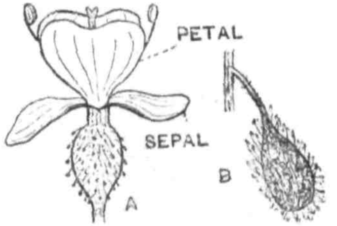

Fig. 126.—A, Flower; B, Fruit of Enchanter's Nightshade.

125 B, C), or in flowers with a very short tube, *e.g.* Moschatel, Bedstraw, Enchanter's Nightshade (fig. 126), or in various shallow open flowers, *e.g.* Saxifrages (fig. 125 A) Stonecrop (fig. 127). They can of course visit any shallow flowers, and at least get pollen from honeyless "pollen-flowers," *e.g.*

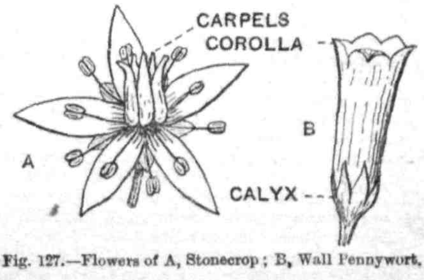

Fig. 127.—Flowers of A, Stonecrop; B, Wall Pennywort.

Wood Anemone, Clematis, Poppy (figs. 128, 129), Dog Rose, Rock Rose, St. John's Wort. Some flowers show remarkable adaptations for pollination by flies, which are much lower in intelligence than the other classes of flower-visiting insects.

reach it. The honey may be slightly concealed by the stamens—*e.g.* Buttercup, Stitchwort; by the erect, stiff sepals in the smaller Crucifers; by the formation of a shallow receptacle-cup in many Rosaceae—*e.g.* Strawberry, Cinquefoil; or by a short corolla-tube—*e.g.* the shorter-tubed Composites, All-Heal (*Valeriana*), Guelder Rose. Such flowers are visited by the longer-tongued beetles and flies, as well as by insects of higher type.

277. **Flowers with fully Concealed Honey.** This type of flower differs only in degree from the last. Here the honey is out of the reach of the short-tongued insects, and can only be obtained by those having tongues about 6 mm. long, including the longest-tongued flies (chiefly the hover-flies) and the shorter-tongued bees — *e.g.* burrowing-bees — and wasps. The concealment of the honey is effected by a further deepening of the flower, due to formation of a receptacle-tube, or to the sepals or petals (or both) growing out vertically from the receptacle (instead of spreading as in shallow flowers), and in many cases being joined below to a tube —*i.e.* being gamosepalous or gamopetalous. Examples of these medium-tubed flowers are seen in Blackberry, Currants, Gooseberry (fig. 131), Pasque Flower, Willow-herb (fig. 132), Geranium, Speedwell, Mint (compare these to see how the tube is formed in each case, and try to find other examples).

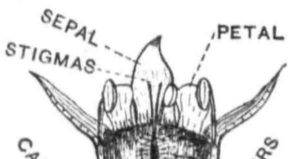

Fig. 131.—Vertical Section of Flower of Gooseberry.

278. **Wasp-Flowers.** Wasps visit various flowers which are adapted also for the smaller bees. Some flowers are largely visited by wasps—*e.g.* Figwort (Art. 249), Snowberry, Barberry. Wasps seem generally to begin with the upper flowers on a plant and work downwards, whereas bees usually begin with the lowest flowers and

work upwards. Try to verify this by watching wasps at work on the Figwort and bees on, say, a Monkshood, and then try to explain what advantage as regards cross-pollination (the bringing of pollen from

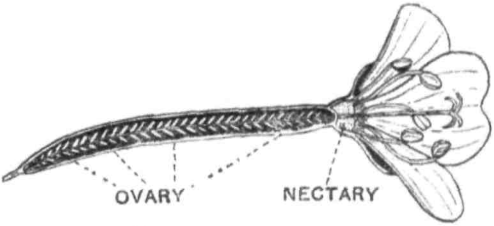

Fig. 132.—Vertical Section of Species of *Epilobium*.

another plant, not from a flower on the same plant) the Figwort gains by being protogynous (a comparatively rare feature in insect-pollinated flowers).

279. **Long-tubed Flowers.** When the flower-tube becomes longer, all these shorter-tongued insects are more or less completely excluded, and the flower is adapted for, and chiefly visited by, the larger bees (hive-bees and humble-bees), butterflies, and moths. Most flowers belonging to the Lily, Daffodil, and Iris families of Monocotyledons come under this type; the perianth is nearly always a long tube (Arts. 251–3). In most long-tubed flowers the honey is found only in the lower part of the tube, but in Crocus it fills the space between the style and the very long perianth-tube, and is therefore easily reached by bees and butterflies. Flowers like those of Papilionaceae, Snapdragon, and Toad-flax can only be opened by large bees, and only the longest-tongued bees can reach the honey in such flowers as Monkshood and Larkspur. Humble-bees have longer tongues (8 to 12 mm.) than hive-bees and other bees (4 to 7 mm.) that can find concealed honey; the humble- and hive-bees have the most perfect mechanism (the "pollen-baskets" on the hind-legs) for collecting pollen to feed their brood, and they alone mix the pollen with honey for this purpose. Humble-bees are particularly skilful in finding the way to well-concealed honey. In this connection compare Red Clover and White Dead-nettle (humble-bees)

with White Clover and Red Dead-nettle (smaller bees). Blue, purple, and red colours are often associated with flowers visited by bees and butterflies, while flowers visited by other insects are usually white, yellow, or variegated; but there are far too many exceptions to allow of a general rule. Blue, purple, and red colours appear to have a special attraction for bees.

280. **Special Mechanisms in Bee-visited Flowers.** There are some special arrangements associated with flowers visited chiefly by bees and wasps which have not so far been mentioned here, and of which a few examples may be given. Examine the flowers of—

Exp. 357. *Barberry.* What peculiarity is shown by the stamens? Push a pointed pencil or match-stick into the flower, imitating the action of a bee or wasp probing for the honey at the bases of the stamens, and notice what happens.

Exp 358. *Primrose.* Examine the two kinds of flower, short-styled (thrum-eyed) and long-styled (pin-eyed), found on separate

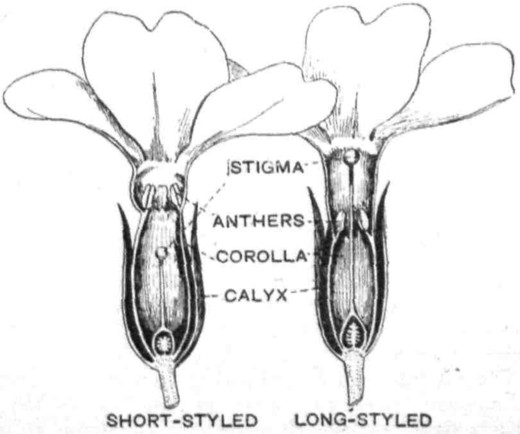

Fig. 133.—Vertical Sections of Short-styled and Long-styled Flowers of Primrose.

plants, and note the relative positions of anthers and stigma in the corolla-tube in each case (fig. 133). In which case is self-pollination

prevented? Cover flowers of each kind with muslin, and find out whether self-pollination does occur in either kind. With the microscope examine the pollen-grains and the stigma of each kind of flower, noting that the higher anthers produce larger pollen-grains, while the longer style has longer hairs on the stigma; how will these differences help in promoting cross- and preventing self-pollination? Examine other flowers which are *dimorphic* like Primrose—*e.g.* Lungwort, Wood Sorrel—also Purple Loosestrife (common on river-banks) which is *trimorphic*, with *three* forms of flower (on distinct plants), each having two sets of stamens differing in length and a style which may be (1) above both sets, (2) below both sets, or (3) between the two sets. In all these *heterostyled* flowers, the longer the style is, the longer are the stigmatic hairs, and the longer the stamens the larger are the pollen-grains.

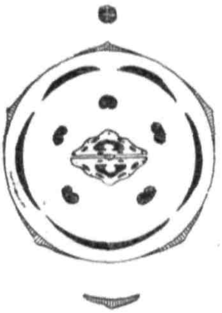

Fig. 134.—Floral Diagram of Primrose.

Exp. 359. *Campanula, Heather, Bilberry.* In nearly all flowers with a corolla-tube (gamopetalous), the stamens have their filaments inserted on the tube (epipetalous). The chief exceptions to this rule

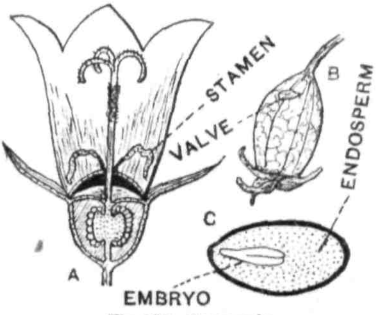

Fig. 135.—*Campanula.*

A, Vertical Section of Flower; B, Fruit; C, Longitudinal Section of Seed.

occur in the Campanula family (Harebell, Canterbury-bell) and the Heather family (Heather, Ling, Bilberry, Rhododendron).* It is

* The stamens are free in the Wall Pennywort (*Cotyledon*), but this is exceptional in its family (Crassulaceae) in being gamopetalous.

obvious that in most gamopetalous flowers free stamens would mean an unnecessary waste of material, but why these exceptions?

Fig. 136.—Sprig of Cross-leaved Heather (*Erica Tetralix*).

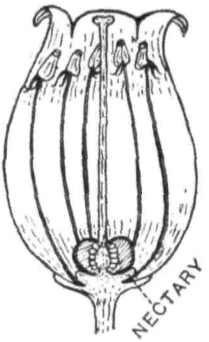

Fig. 137.—Vertical Section of Flower of *Erica*.

Examine Harebell (or Canterbury-bell) flowers of different ages and note how the broad bases of the stamens cover the honey, how at first the anthers surround the style and shed the pollen on it and then fall outwards, and how the stigmas then separate (stage shown in fig. 135). Compare this mechanism with that of Composites and find out how it works, noting the position of the flower (drooping or erect?), how insects enter it (do they place their feet on inner side of corolla, or on the style?), whether self-pollination occurs (cover flowers with muslin). In Heather (figs. 136, 137) and Bilberry (fig. 138), note the peculiar horn-like appendages on the outer side of each anther, and the two pores by which the anther opens. A bee entering the drooping flower rubs against the stigma and then, in pushing up its proboscis for the honey, comes against the anther-appendages and shakes the anthers, bring a shower of pollen down on its head. It is easy to see why the stamens are free from the corolla in these cases, for mechanical reasons.

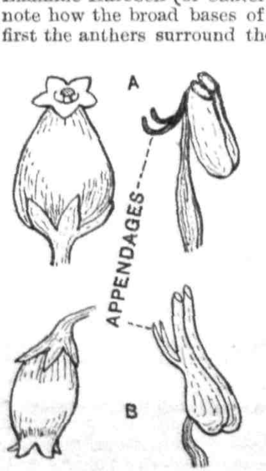

Fig. 138.—Flowers and Stamens of A, Bearberry; B, Bilberry. Both belong to Ericaceae.

Exp. 360. *Pansy and Violet.* Examine the flowers of Pansies and Violets. In Pansy (fig. 139) notice the spur which is formed by the anterior petal, and into which descend two appendages from the

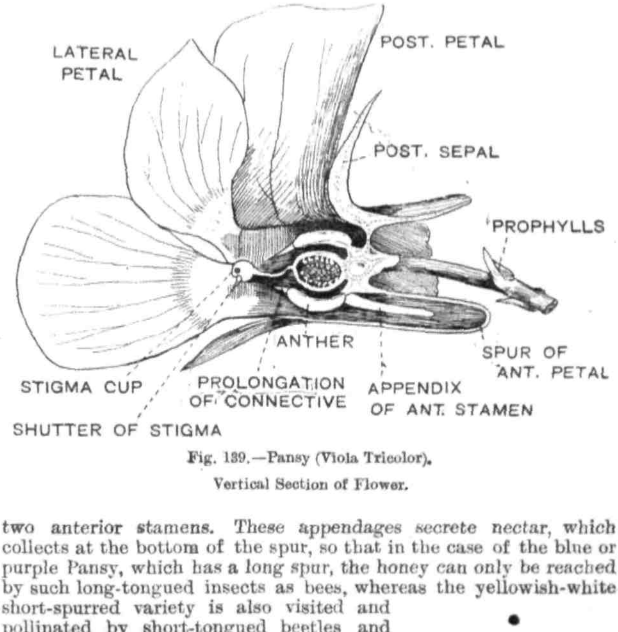

Fig. 139.—Pansy (Viola Tricolor).
Vertical Section of Flower.

two anterior stamens. These appendages secrete nectar, which collects at the bottom of the spur, so that in the case of the blue or purple Pansy, which has a long spur, the honey can only be reached by such long-tongued insects as bees, whereas the yellowish-white short-spurred variety is also visited and pollinated by short-tongued beetles and flies.

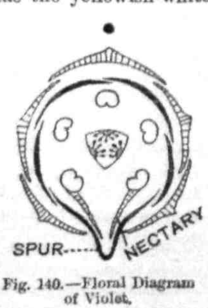

Fig. 140.—Floral Diagram of Violet.

The stigma is placed in a pit on the anterior surface of the knob at the end of the style, and beneath it is a small comb-like scraper or valve. As the bee introduces his proboscis, covered with pollen, he rubs against the upper edge of this valve, depositing pollen upon the stigma. Any pollen scraped off as the proboscis is withdrawn will tend to fall away from the stigma. This is hence an adaptation to prevent self-pollination, and a portion of the pollen will be deposited on the stigma

of the next flower visited as the bee thrusts his proboscis past the shutter of the stigma to reach the nectar in the spur.

In other ways also the mechanism of the Violet or Pansy flower is so highly specialised, that when cross-pollination fails, no fertilisation of the ovules is possible, and the seeds are unable to develop. Hence in many of the common wild Violets special small green flowers are produced late in the year, which do not open, but pollinate themselves and set seed. These *cleistogamic* flowers have minute petals and few stamens (why?); the pollen-grains germinate inside the anthers.

281. **Butterfly- and Moth-Flowers.** When the flower-tube (or at any rate the level of the honey) is more than about 12 mm. (about half an inch) deep, the honey is beyond the reach of bees, though they may visit the flower for pollen or the humble-bee may bite through the tube (calyx or corolla) and thus rob the flower of its honey. Good examples of butterfly-flowers are seen in the Pinks, Red

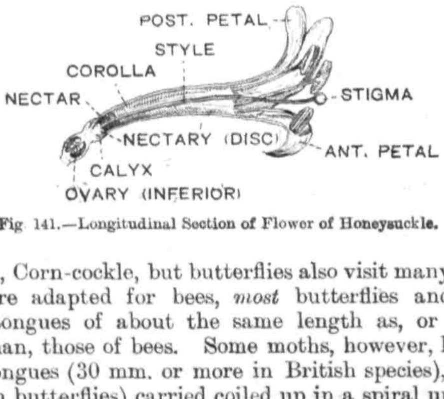

Fig. 141.—Longitudinal Section of Flower of Honeysuckle.

Campion, Corn-cockle, but butterflies also visit many flowers which are adapted for bees, *most* butterflies and moths having tongues of about the same length as, or a little longer than, those of bees. Some moths, however, have far longer tongues (30 mm. or more in British species),* which are (as in butterflies) carried coiled up in a spiral under the head when flying. These moths can reach honey even when it is at the bottom of a very long tube, as in the Honeysuckle (fig. 141), which is visited chiefly by the night-flying Privet Hawk-moth, and the White Convolvulus, which

* In some foreign moths the proboscis reaches the astonishing length of 300 mm. (about 12 inches).

is pollinated by another species of Hawk-moth (*Sphinx convolvuli*, tongue 80 mm. long), and rarely sets seed in England owing to the rarity of this moth. Other flowers pollinated by night-flying moths are the White Campion

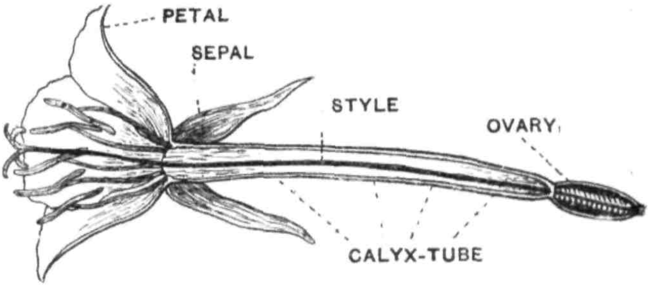

Fig. 142.—Vertical Section of Flower of Evening Primrose.

(*Lychnis vespertina*), Evening Primrose (fig. 142). Moth-pollinated flowers are white or pale-coloured, sweetly scented, and open in the evening, usually remaining closed and almost scentless during the day.

282. **The Flower-Tube.** It is interesting to compare the various ways in which the flower becomes tubular in form, so as to protect the ovary, to conceal the honey, to shelter the pollen from rain, to exclude short-tongued insects, etc. The study of development shows that, starting from the simple "hypogynous" condition, the formation of a "perigynous" or "epigynous" flower, of a "gamophyllous" perianth, of a "gamosepalous" calyx, of a "gamopetalous" corolla, of "epipetalous" stamens, etc., in short, all the cases of "cohesion" and "adhesion" are due to the growth of the receptacle during the flower's development, and that all these conditions in the mature flower are due to differences in the extent of this growth. It is important to remember this, as the various terms in current use tend to obscure the facts of development, and even to imply that actual "fusion" occurs after the various flower-parts have been developed.

283. **Protection against Rain.** The flowers already mentioned show examples of the various ways in which the pollen may be protected against rain. Pollen-grains, like seeds, are much less resistent to extremes of temperature and to drying when once they have been moistened and have begun in consequence to germinate. In some flowers, especially those whose pollen is exposed to rain when the flower opens, the pollen-grains are not readily wetted, having a covering of wax or of spines, etc. In most cases, however, the grains lose their power to germinate if wetted and then allowed to dry. Many flowers protect the pollen by their drooping position, *e.g.* Heather, Harebells, Lily of the Valley, Solomon's Seal; in some cases the stalk bends down at night or in bad weather, *e.g.* Violet, Foxglove; or the flower closes up under similar conditions, *e.g.* Tulip, Crocus, Lesser Celandine, Scarlet Pimpernel (in which self-pollination often occurs in the closed-up flower, by the stamens touching the stigma), and the same kind of closing is effected in many Composites by the movements of the bracts. In Iris the large petaloid stigmas cover the stamens, while in Orchis the single stamen is covered by the hood formed by the three upper perianth-lobes.

284. **Wind-Pollinated Flowers.** Many flowers which contain no honey are visited for pollen by insects, attracted by the colours or scents of these "pollen-flowers." Several examples have been mentioned. This leads to the consideration of flowers which have neither honey, scent, nor conspicuous colours, and which are seldom or never visited by insects. Such flowers are chiefly pollinated by the wind.*

Exp. 361. *Comparison of Willow and Poplar.* Examine and compare the flowers of Willow and of Poplar, which are very closely allied plants. In both cases the male and female flowers are on separate plants, and are carried on special branches (catkins), a

* In a few water-plants the pollen is carried by water, and pollination occurs at or below the surface, but this is rare; most aquatic plants raise their flowers well out of the water, and are pollinated by wind or by insects.

Fig. 143.—The Willow, with Male (lower) and Female (upper) Catkins.

Fig. 144.—The Poplar—Twig and Male Catkin.

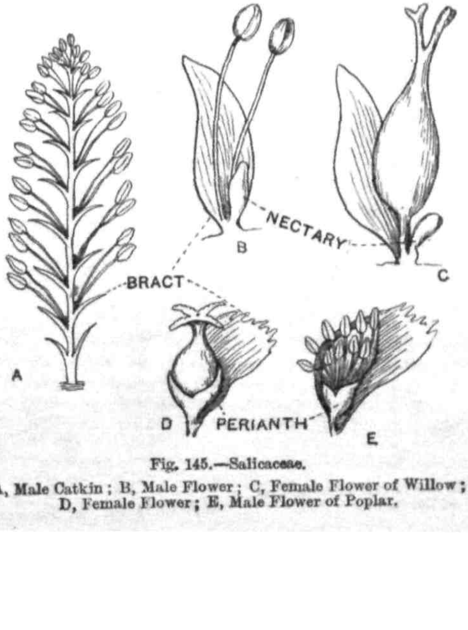

Fig. 145.—Salicaceae.

A, Male Catkin; B, Male Flower; C, Female Flower of Willow; D, Female Flower; E, Male Flower of Poplar.

catkin consisting of an axis bearing numerous flowers, each flower standing in the axil of a bract. In Willows the male catkins are bright yellow, the female ones green, when the flowers open. Each male flower consists of two (in some species more) stamens, with a honey-gland at their base (fig. 145 B); the female flower of a pistil with two stigma-lobes (each often forked at the end), ovary one-chambered with numerous ovules on two parietal placentas, and a honey-gland (fig. 145 C). The flowers are largely visited by bees seeking for honey and pollen among the scanty spring flowers. In Poplars each male flower has a larger number of stamens (twenty to thirty), surrounded at the base by a cup-like outgrowth ("perianth"), and the female flower of a pistil (similar in structure to that of Willows) with branched stigmas forming a tuft (fig. 145 D, E); in neither case is there a honey-gland. The Poplars are wind-pollinated; their flowers have no honey to attract insects. More pollen is produced than in Willows, and the stigmas are more branched, exposing a larger surface; the catkins of Poplars hang down loosely and swing in the wind (fig. 144), and are longer than those of Willows, which usually stand out stiffly from the stem (fig. 143). Moreover, Poplars flower before the leaves appear, and their flowering is generally over by April, when most Willows are beginning to flower; many Willows flower at the same time that the leaves expand.

285. **Fagales** (**Cupuliferae**). Many forest-trees bear their flowers (or at least the male flowers) in catkins, or in clusters resembling

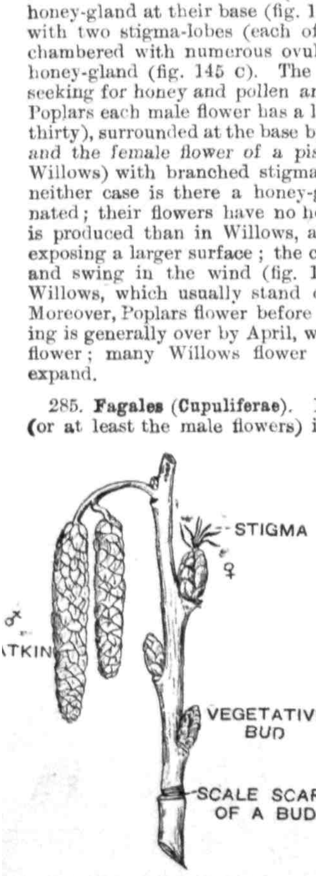

Fig. 146.—Male and Female Inflorescences of the Hazel.

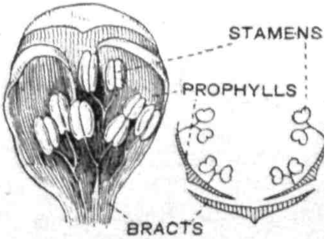

Fig. 147.—Hazel.
A, Male Flower; B, Diagram of same.

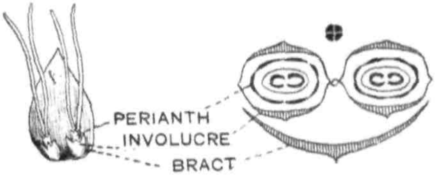

Fig. 148.—Two Female Flowers of Hazel in Axil of a Bract, each with two long Stigmas, and Diagram of same.

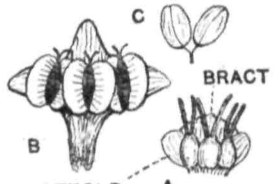

Fig. 150.—Birch.

A, Female flowers in axil of bract; B, Fruiting scale, with three samaras; C, stamen from male flower.

Fig. 149.—Birch.

Twig showing male and female catkins.

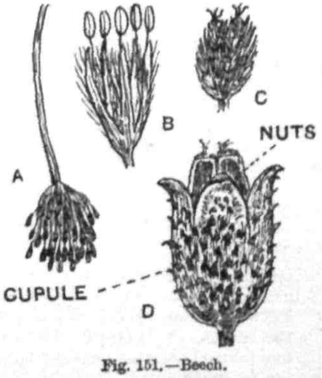

Fig. 151.—Beech.

A, Male inflorescence; B, Male flower; C, Female inflorescence; D, Cupule with nuts.

catkins, but have the male and female flowers on the same plant. In Birch, Alder, and Hazel (figs. 146-50) the male catkins hang down, so that the stamens are covered by the scales (bracts) to which they are attached (as in Poplar), and thus protected from rain. The female catkins are smaller, with stigmas projecting beyond the scales. In Hazel and Alder the catkins are formed from

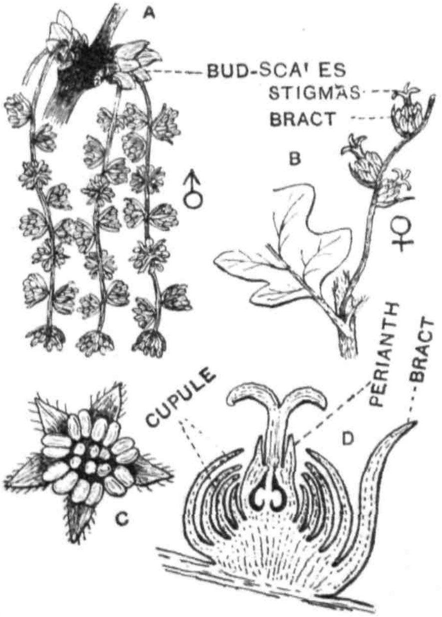

Fig. 152.—Oak

A, Male; B, Female inflorescences; C, Male flower; D, Female flower in section.

special buds, and are nearly mature in the autumn, ready to open early in spring, before the leaves. In Birch the catkins are formed in the ordinary buds, and the flowers therefore appear along with the leaves. This is also the case in Beech and Oak, in which the male flowers have a cup-like "perianth"; in Beech the male flowers are in a cluster at the end of a long drooping stalk (fig. 151), in Oak they are scattered along a similar stalk (fig. 152).

286. **Other Wind-Pollinated Flowers.** We have seen that plants with wind-pollinated flowers occur in some families which are chiefly insect-pollinated—*e.g.* Meadow-rue (*Thalictrum*) in Ranunculaceae, Salad Burnet (*Poterium*) in Rosaceae. Compare their flowers with those of allied plants in the same family. Examine also the following wind-pollinated flowers:

Ash. Flowers appear before leaves; usually complete, but male and female flowers may occur on the same tree; complete flowers are protogynous, consisting of two stamens and a pistil with two

Fig. 153.
Flower of Ash.

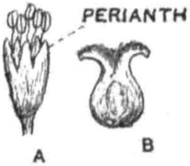

Fig. 154.—Elm.
A, Flower; B, Pistil.

stigmas (fig. 153). The Manna Ash of Southern Europe has calyx and corolla; most of the family (Oleaceae) to which Ash belongs are insect-pollinated—*e.g.* Lilac (bees and butterflies), Jasmine (night-moths)—and have a tubular corolla.

Elm. Flowers appear before leaves; flower complete, with a lobed cup (perianth), a stamen to each lobe, and a pistil with two stigmas (fig. 154).

Pine, Larch, Yew. In these plants the stamens and carpels are on special branches (cones), the pollen is produced in enormous abundance, and the ovules are exposed, so that the pollen-grains reach the micropyle directly.

Stinging-Nettles. Flowers small and green, male and female either on separate plants or on the same plant; in male flower the stamens

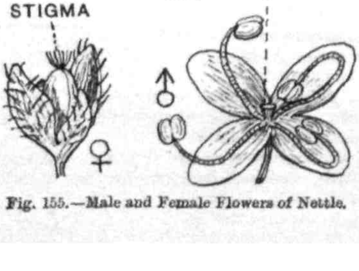

Fig. 155.—Male and Female Flowers of Nettle.

are at first folded inwards and downwards, but on warm, dry days they spring up violently and scatter the pollen in a cloud. Cut off a branch bearing male flowers, and observe this on touching the coiled-up stamens or warming the flowers. Female flower with a tufted stigma (fig. 155).

Dog's Mercury. Flowers small, green, dioecious; stamens numerous; two large stigmas (fig. 156).

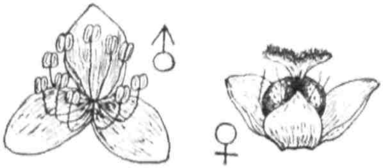

Fig. 156.—Male and Female Flowers of Dog's Mercury.

Plantain. Flowers in a spike, markedly protogynous; when the stamens of the lower (older) flowers hang out, after the withering of the stigmas, the stamens of the upper (younger) flowers are still in the bottom of the corolla-tube, and the stigmas projecting out-

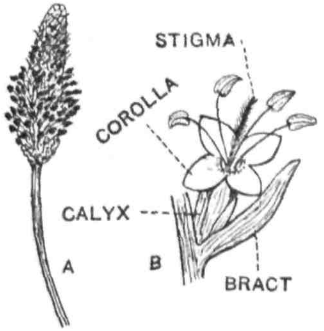

Fig. 157.
A, Spike; B, Flower of Plantain.

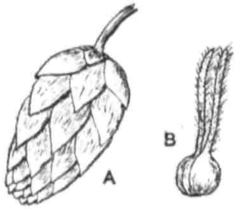

Fig. 158.—Hop.
A, Female inflorescence; B, Pistil of female flower.

wards and ready for pollination (fig. 157). Some species have coloured anthers, and are slightly scented; these are sometimes visited by insects for pollen.

Other wind-pollinated flowers which you should examine are those of Hop (fig. 158), Sedges, Rushes, Docks, Crowberry, Walnut, Oriental Plane.

287. Characters of Wind-Pollinated Flowers. In wind-pollination it is obvious that the chances of a pollen-grain striking a stigma are very small, and that the plant must therefore produce a much larger amount of pollen than is the case in insect-pollination. In order to increase the chances of pollination the pollen is light, and can therefore float for a considerable time in the air and be carried to a great distance, while the stigmas are usually large and branched, to increase the amount of their surface. In many wind-pollinated trees the inevitable waste of pollen is to some extent reduced by the flowers opening before the leaves have unfolded, or before they have grown large enough to form a serious obstacle to the wind-carried pollen. In most herbaceous plants with wind-pollinated flowers the latter are carried up on a long stalk, well above the leaves, so as to expose them as freely as possible to the wind. It will be noticed that many wind-pollinated plants have the stamens and the pistil in separate flowers, either on the same plant or on separate plants, and that when they are both present in the same flower the stigma nearly always matures before the anthers open.

QUESTIONS ON CHAPTER VI.

1. What is the usual function performed by the various parts of the flower? Have you observed any cases in which functions other than the usual ones are performed by floral structures? Show by numerous examples that the division of the flower into four whorls cannot always be rigidly maintained.

2. Give an account of the development, structure, and function of a pollen-grain.

3. Describe the process by which, after the pollen-grains have reached the stigma, the fertilisation of the ovules is effected.

4. Describe the processes which lead to the conversion of an ovule into a seed, and state what is the difference between albuminous (endospermic) and exalbuminous (non-endospermic) seeds, giving examples.

5. Describe the situation in which honey is produced in any three flowers you have examined. How does it profit a plant to expend its substance in the production of honey? How is it that some plants dispense with the production of honey? Name three such plants.

6. Selecting from each of the families Leguminosae and Labiatae any flower which you have studied, describe its structure, and explain the arrangements by which pollination is effected.

7. Describe the flower of the Rose, and explain why it is said to be perigynous.

8. Give diagrams, with brief descriptions, showing the variation in the form of the ovary and receptacle in the Rosaceae. Give examples of each case. Name the chief British genera of this order.

9. Draw the flowers of any three of the following: Figwort, Snapdragon, Foxglove, Salvia, Monkshood, Sweet Pea, Dead-nettle. What do you know of the method of pollination in the flowers you draw? Explain the connection, if any, between the methods of pollination and the time of year at which the flowers appear.

10. Mention a flower which is naturally self-fertilised, and another which is naturally cross-fertilised. What could you do to aid cross-fertilisation in the first, and self-fertilisation in the second case? Is the seed produced by cross-fertilisation better or worse than that produced by self-fertilisation?

11. Explain, and illustrate by means of examples, the following terms relating to the stamens of flowers: tetradynamous, didynamous, diadelphous, syngenesious. What is the meaning of the statement that the flower of the Orchidaceae is gynandrous?

12. Describe the arrangement of the stamens in the Cruciferae, the Labiatae, and the Primulaceae.

13. Describe, with examples, the structure of (1) a hypogynous, (2) a perigynous, and (3) an epigynous flower.

14. Briefly describe, giving examples, the following forms of inflorescence, and point out the relationship which exists between them: spike, spadix, raceme, head, panicle, umbel.

15. State what is the essential difference between *definite* and *indefinite* inflorescences, describing, with examples, the principal varieties of each.

16. What is meant by a floral receptacle? What part does it play in our conception of the structure of the flower?

17. Name any plants you know in which the flowers are massed in close, flat-topped inflorescences, and mention the advantages which you suppose are obtained by such an arrangement. Name any natural orders that are characterised by this type of inflorescence, and describe, with instances, the differentiation (modification) which the marginal flowers may undergo.

18. In what respects does the flower-head of a Daisy resemble a flower? Show that it is really an inflorescence.

19. Show by drawings the structure of a complete flower of the Compositae. Explain how the flowers of Daisy, Dandelion, and Thistle differ from one another.

20. What flowers have you yourself observed being visited by wasps, by butterflies, by flies? What insects have you yourself seen at Sweet Pea, Primrose, Buttercup? Supplement this answer by information obtained in other ways, but distinguish carefully between observations and theories, facts and expectations.

21. Describe the inflorescence of a Daisy and of a Dead-nettle, pointing out the features of (*a*) resemblance, (*b*) difference, existing between them.

22. Describe the process of pollination in any *two* of the following: Larkspur, Willowherb (*Epilobium*), Dead-nettle, Willow.

23. Describe any arrangements which are adapted to secure cross-pollination in three different Ranunculaceous flowers.

24. Describe the flowers of the Primrose, and explain the adaptations for pollination.

25. What is heterostylism, and what is its importance? Give examples of heterostyled British plants.

26. Mention any flowers you know which are pollinated by the wind. Describe the structures involved in pollination in each case, and show how they differ from the corresponding structures in insect-pollinated flowers. Have you noticed any other features of wind-pollinated flowers, such as habitat or time of flowering, which you can connect with wind-pollination? Give instances.

CHAPTER VII.

FRUITS AND SEEDS.

288. **How Fruits are Formed.** The influence of fertilisation extends from the developing seeds to the surrounding parts, causing a renewal of active growth not only in the carpels, but often in other parts of the flower as well. Usually, however, the stamens and corolla persist for a shorter time than they would have done had not fertilisation occurred. The ultimate result of fertilisation is the formation of a fruit. The simplest definition of a fruit is that it consists of the parts of a single flower which persist and grow after fertilisation. This definition covers most fruits, which may be divided into *simple* and *aggregate*. A simple fruit is formed from one free carpel, as in the Bean, or from several united carpels (syncarpous pistil), as in the Poppy. An aggregate fruit is formed from several free carpels, as in Buttercup, Blackberry. The wall of the ovary becomes the *pericarp*, or fruit-wall, which may, as the fruit ripens, either remain soft and fleshy or become dry and hard. Whether the fruit is dry or fleshy depends on the amount of water it contains when ripe. Dry fruits which contain several seeds usually open so as to set the seeds free, the pericarp breaking apart to form an opening. Some dry, many-seeded fruits, however, split into pieces, each containing a single seed. These two types are distinguished as (1) Opening or Capsular fruits; (2) Splitting or Separating fruits. Dry one-seeded fruits, and practically all fleshy fruits, remain closed, and the seeds escape by the decay of the pericarp, or the latter may only be broken when the seed germinates. This third type may be called (3) Closed or Indehiscent fruits.

289. **Opening or Capsular Fruits.** The *follicle* opens along the side which bears the seeds—*i.e.* the ventral suture (figs. 159, 160). The *pod* (legume) separates into two

Fig. 159.—Collection (Eterio) of Follicles of Monkshood

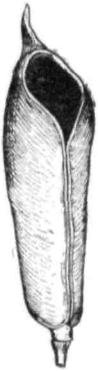

Fig. 160.—Follicle of Larkspur (Delphinium ajacis).

valves by opening along both dorsal and ventral sutures (fig. 161). The *siliqua* (characteristic fruit of Crucifers) opens by two valves which separate from below upwards,

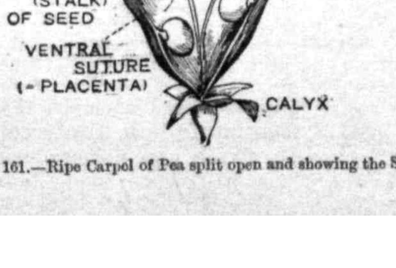

Fig. 161.—Ripe Carpel of Pea split open and showing the Seeds.

leaving the seeds on the edges of a partition across the fruit (fig. 162). The *silicula* is a short and broad form of the siliqua (Shepherd's Purse and other Crucifers).

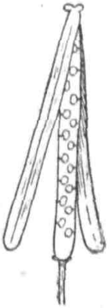

Fig. 162.—Fruit of Wallflower.

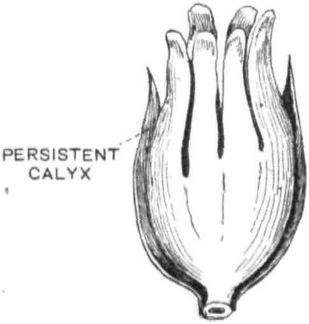

Fig. 163.—Capsule of Stitchwort opening by Six Teeth.

A typical *capsule* usually consists of several carpels, and is dry. The capsules of Horse Chestnut are rather fleshy when ripe, and the fleshy capsules of the Balsam and

Fig. 164. Transverse Dehiscence of Capsule of Plantain.

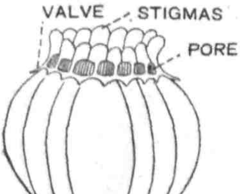

Fig. 165.—Capsule of Poppy with Poral Dehiscence.

Wood-sorrel are so much stretched when ripe that a touch is sufficient to cause them to split open and throw the seeds out violently. Capsules usually open longitudinally, either

along the dorsal sutures (midribs) of the carpels (*e.g.* Bluebell) or along the partitions between the chambers of the ovary (*e.g.* Foxglove, Rhododendron). The capsule of Stitchwort (fig. 163) and other Caryophyllaceae splits about half-way down into twice as many teeth as there are carpels. In all these cases the opening takes place along lines already marked out in the structure of the ovary; but in some plants it follows entirely new paths. Thus some capsules open transversely, a lid being separated, as in Plantain (fig. 164) and Pimpernel; while in the Poppy small pieces of the capsule-wall are detached, forming a series of holes around the top of the capsule, through which the seeds escape (fig. 165).

Closed (indehiscent) fruits may be either dry, in which case they are one-seeded, or fleshy.

290. **Dry Closed Fruits** are given various names, but the two chief types are (1) the *nut*, with hard woody pericarp—*e.g.* Hazel, Oak (Acorn); (2) the *achene*, with leathery or

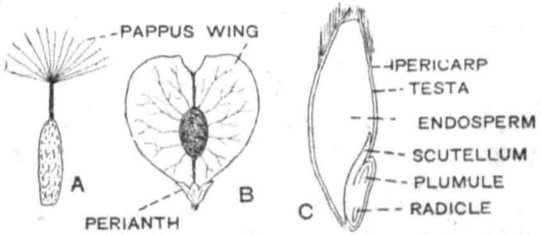

Fig. 166.—Achenial Fruits.

A, Cypsela, or achene with pappus; B, Samara or winged achene of Elm; C, Achene or caryopsis of Oat (longitudinal section—bract and bracteole removed).

membranous pericarp—*e.g.* Buttercup, Sunflower, Grasses. The achenes of Composites often have a tuft of hairs, the *pappus* (= calyx), at the top—*e.g.* Thistle, Dandelion, Groundsel. Those of Elm, Birch, Ash, etc., have a membranous wing. (See figs. 166-8.)

291. **Fleshy Fruits.** A few fleshy fruits open to let the seeds escape—*e.g.* Horse-chestnut and some Gourds. Three types of closed fleshy fruits can be recognised: (1) the *berry*, in which the pericarp is soft and fleshy throughout except for the membranous skin; (2) the *drupe*, in which

Fig. 167.—Bract of the Birch with Three Winged Achenes in its Axil.

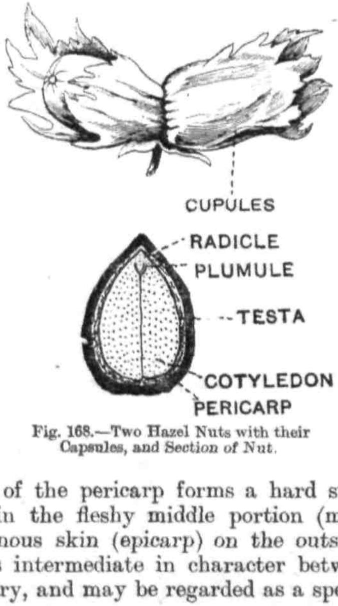

Fig. 168.—Two Hazel Nuts with their Capsules, and Section of Nut.

the innermost portion of the pericarp forms a hard stone (endocarp) embedded in the fleshy middle portion (mesocarp), with a membranous skin (epicarp) on the outside; (3) the *pome*, which is intermediate in character between the drupe and the berry, and may be regarded as a special form of the latter.

292. **Drupes.** A simple drupe (fig. 169) is formed from a single free carpel, and has one stone with one seed inside it—*e.g.* Plum, Cherry. Drupes may, however, be syncarpous, in which case each chamber of the ovary may form a distinct stone or drupe. The so-called "berries" of Holly and Elder are really compound drupes of this kind. The Walnut is a drupe from which the mesocarp (flesh) peels off during ripening, and allows the stone, enclosing a single

seed, to escape. The Coco-nut (fig. 170) is a drupe in which the mesocarp is fibrous instead of being fleshy. The shell of the Coco-nut is the endocarp,* the flesh inside it is

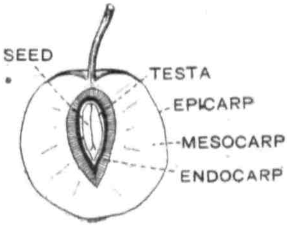

Fig. 169.—Drupe of Cherry cut Longitudinally.

endosperm, and in it lies a small embryo below one of the three pits at the end of the "nut." This früit is formed from a three-chambered ovary, only one chamber being fertile; the space in the centre of the "nut," filled with

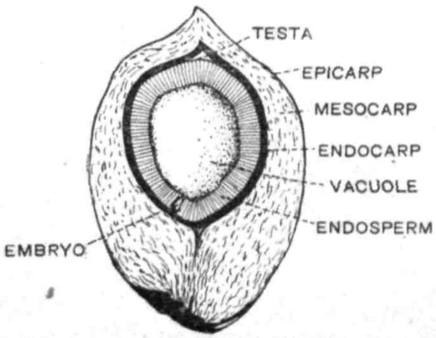

Fig. 170.—Fruit of Coco-nut cut Vertically.

sap, corresponds to the vacuole in the young embryo sac. The Almond also has a fibrous endocarp; it sometimes contains two seeds.

* The epicarp and the fibrous mesocarp of the Coco-nut are removed before exportation.

293. **Berries** usually contain several seeds, but sometimes only one, as in Dogwood and Date. The berry is distinguished from the drupe by the fact that the hard part, or "stone," in a berry is the seed itself, whilst the stone in a drupe is the innermost part of the fruit-wall, and encloses the seed.

The Banana, Currant, Cucumber, Cranberry, Grape, Gooseberry, Orange, Pomegranate, and Tomato are all berries, although several of them exhibit special peculiarities. In the case of the Gooseberry and Pomegranate, the outer layer of the coat of each seed is succulent, and forms a large part of the fruit. The "quarters" of the Orange correspond to the carpels, and the juicy part is composed of large hairs, which arise from the walls of the carpels and are filled with watery sap. The squirting Cucumber (*Ecballium*) becomes highly tense and turgid when ripe, so that when detached from the stalk the seeds are violently ejected along with a quantity of watery sap.

294. **Pomes.** The Apple or Pear affords the best example of a pome (fig. 171), being developed from an inferior ovary composed of five imperfectly syncarpous carpels. The outer fleshy part of an apple is really a portion of the receptacle, while the parchment-like membrane which forms around the wall of each chamber of the ovary is mainly carpellary in origin.

Pomes also occur in Quince, Medlar, and Hawthorn. See Art. 246 and Fig. 92, p. 251.

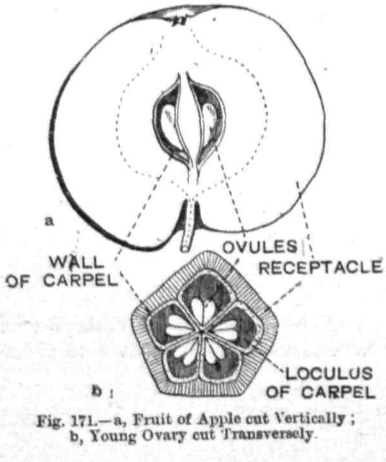

Fig. 171.—a, Fruit of Apple cut Vertically; b, Young Ovary cut Transversely.

295. **Splitting or Separating Fruits (Schizocarps)** are so called because they split into two or more one-seeded parts.

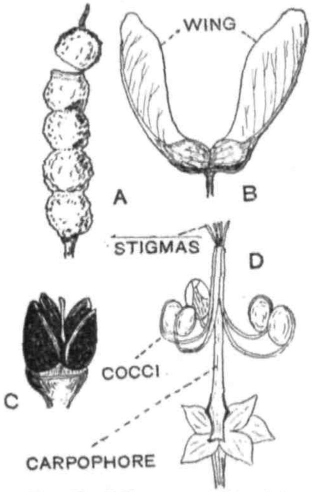

Fig. 172. Schizocarps splitting into several Pieces.
A, of Hedysarum; B, of Maple; C, of Lamium; D, of Geranium.

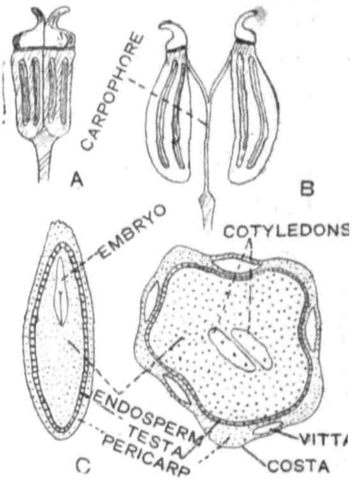

Fig. 173.—Schizocarp of an Umbellifer.
C, Longitudinal and transverse sections of fruit of the Caraway.

Examples are seen in Sycamore and Maple (fig. 172 B), Umbellifers (figs. 173, 174), Geranium (fig. 172 D), the Labiate and Borage families (fig. 172 C), Mallow (fig. 175).

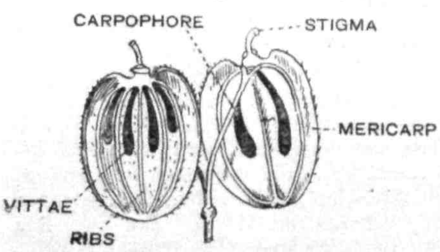

Fig 174.—Schizocarp of Heracleum (Cow Parsnip).

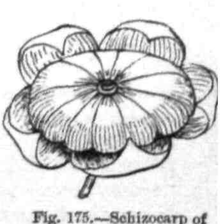

Fig. 175.—Schizocarp of Mallow.

In some Leguminosae (*e.g. Hedysarum*, the "French Honeysuckle") and some Crucifers (*e.g.* Radish) the fruit splits across into one-seeded pieces, and is called a *lomentum* (more strictly, a lomentaceous pod, or siliqua, as the case may be), fig. 172 A.

The one-seeded parts into which a schizocarp splits do not usually open to let the seed out; but this does occur in some cases (*e.g.* Spurges, Geranium).

296. **Aggregate Fruits** may consist of a number of follicles, as in Christmas Rose, Marsh Marigold, Monkshood (fig. 159), or of a number of achenes inserted on a convex receptacle, as in Anemone or Strawberry, or inside a concave receptacle, as in Rose, or they may consist of drupes on a convex receptacle, as in the Blackberry or Raspberry. Notice in each case whether the receptacle is dry or fleshy.

297. **Special Types.** The fruits developed from a group of flowers or dense inflorescence are often aggregated in closely packed clusters, such as are formed by the fleshy red berries of the Honeysuckle and by the clustered fruits of the Mulberry, the perianths of whose flowers become fleshy and enclose the carpels (fig. 176 B). The Pineapple is a spike-like inflorescence, in which the axis becomes fleshy during ripening, and the individual fruits fuse together. The Hop has an inflorescence consisting of an axis bearing membranous scales, in the axil of each of which there are two female flowers. The scales are shed when ripe with the fruits attached to them. The Fig is formed by a hollow, pear-shaped capitulum bearing male and female flowers, the "seeds" being really achenes (fig. 176 A). The Date is a berry, the hard stone being the seed. The Banana is also a berry which, owing to cultivation, does not produce seeds.

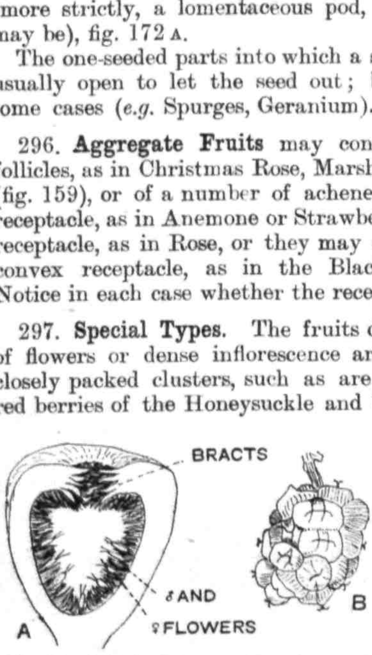

Fig. 176.—A, Fruit of Fig cut in Half Vertically; B, Fruit of Mulberry.

298. **Dispersal of Seeds and Fruits.** Such a plant as a Cherry tree may produce thousands of fruits and fertile seeds in a single season, although none of the latter may succeed in establishing themselves as young seedlings beneath the shade of the parent tree. Even if the parent plant is cut down, or dies at the end of the season, it can hardly make room for more than one or two of its offspring. Hence it is of the utmost importance that the seeds should be afforded some chance of distributing themselves, and reaching localities suitable for the development of new trees. Animals, and especially birds, act as the dispersing agents in this case, frequently carrying the fruit to a distance, and rejecting the hard and inedible stone which protects the seed.

Even in the case of annual plants, the dispersal of the seeds is of great importance, for it is evidently impossible that the thousand or so seeds which a single Sunflower may produce can possibly develop into healthy seedlings on the same area that the adult plant occupied. The means of dispersal adopted by different plants vary widely, and are frequently such as to secure the almost ubiquitous distribution of particular plants. The four commonest agencies by which dispersal is secured are: wind, water, animals, and explosive mechanisms in the fruit itself.

299. **Dispersal by the Wind** is facilitated by the minuteness or lightness of the seeds or fruits, and by the presence of tufts of hairs or wing-like membranes which increase the surface exposed to the wind without appreciably adding to the weight. It is only in the case of dehiscent fruits that mechanisms for dispersal are borne by the seed; closed fruits and the segments of splitting fruits are themselves distributed and possess contrivances for dispersal, while the seeds have none and are carried inside the fruit. The seeds of Orchids are so small and light that, when they are set free by the dehiscence of the capsules, they are freely blown about by the wind. Hence the readiness with which aerial Orchids establish themselves afresh upon the trunks of tropical trees. When the seeds are larger and heavier, the fruit frequently opens in such a manner that

they are jerked out a few at a time, when the wind rocks the seed-bearing capsules to and fro. This is the case with the follicles of the Larkspur and Aconite, with the capsules of the Poppy, and with the capsules of certain members of the Pink family which open so as to form a series of apical teeth. As an aid to wind-dispersal, seeds are frequently flattened (Wallflower), as also are the fruit-segments of Umbelliferae. Small, dry, one-seeded fruits, such as the achenes of the Daisy, are often distributed in a similar

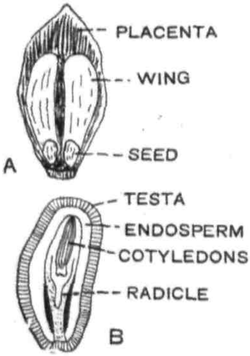

Fig. 177.—Seed of Pine. A, Surface view; B, Longitudinal section.

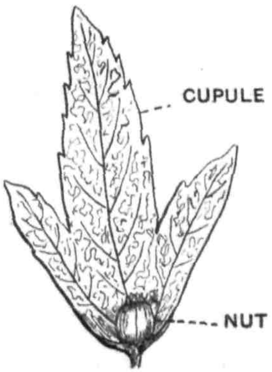

Fig. 178.—Fruit of Hornbeam.

manner. Very commonly, however, special structures are present which enable seeds, or more frequently achenes, to be more readily carried by the wind. The seeds of the Willow, Poplar, Willow-herb (*Epilobium*), and Bog Asphodel have hairy outgrowths, the seeds of the Pine (fig. 177) are winged, as also are those of "Honesty," Yellow Rattle, and of certain tropical Bignonias. The winged achenes (samaras) of the Ash, Elm, and Birch afford good examples of winged fruits in which the wing is an outgrowth of the pericarp. In the Maple and Sycamore each fruit splits into two or three winged samaras (fig. 172 B). The Hornbeam (fig. 178) has persistent bracts which form a wing on

the fruit; a similar bract-wing occurs in the Hop. In the Lime-tree (fig. 179), the stalk bearing the cluster of nuts hangs down, and the large bract attached to it acts as a kite or aeroplane. In Docks the fruit is covered by the perianth, which bears three wings. In some cases the wing is funnel-shaped, or parachute-like, as in Thrift (persistent papery calyx) and Teasel (persistent bracts around the flower).

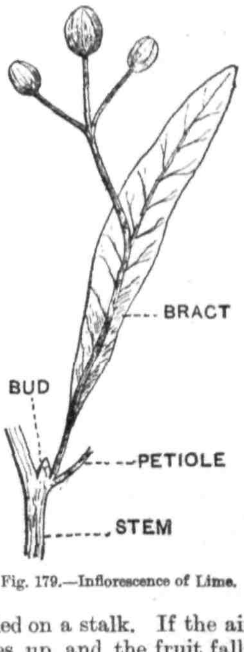

Fig. 179.—Inflorescence of Lime.

A few examples of plumed fruits (*i.e.* fruits bearing hairs or hairy appendages) may be given. In Clematis and some Anemones (*e.g.* Pasque-flower) each achene has a persistent hairy style; in Cotton-grass the fruit bears numerous long silky hairs, produced by the perianth; in Bulrushes, hairs are produced by the stalk on which each fruit is carried. The most highly developed plumed fruits occur in Valerians and most Composites; in these plants the calyx grows after fertilisation, and forms a ring of hairs (the pappus) on the top of the fruit. A good example is seen in the Dandelion and the Goat's beard, where the pappus forms a parachute carried on a stalk. If the air becomes moist the parachute closes up, and the fruit falls to the earth, and is washed into the soil by the first shower of rain. Dispersal by wind involves a greater loss of seeds than dispersal by animals, for the latter usually frequent fertile localities where the seeds have a chance of germinating, whereas wind-dispersed seeds may fall upon sterile or unsuitable localities, or may be carried out to sea. It is for this reason that winged and hairy seeds are usually absent from the plants of the seashore. Hence

also arises the fact that wind-dispersed seeds are usually produced in relatively greater abundance than those dispersed by animals, especially when seeds of the latter class are poisonous or surrounded by specially hard investing layers, so that they cannot be digested.

300. **Dispersal by Water** is uncommon, and occurs chiefly in aquatic plants. The seeds have frequently special air-chambers, which act as floats. These occur between the testa and a special outgrowth, or *aril*, in the case of the Water-lily. Seeds may also be carried on floating timber, or on the mud adhering to the feet of aquatic birds, but these modes of dispersal are largely accidental. The Coco-nut is dispersed by the sea, for the fruits float by means of the light fibrous mesocarp, while the hard endocarp protects the single seed within from injury by the salt water. The Coco-nut palm is usually the first tree to appear on the shore of a newly formed coral island, the fruit being carried by the waves, and the young plant being able to live and grow when its roots, which at first branch throughout the husk, are restricted to sand saturated with brackish or even salt water.

301. **Dispersal by Animals** may be either passive or active. Many fruits possess hooks, and hence may adhere to the wool or fur of passing animals. These adhesive contrivances are usually outgrowths of the fruit and not of the seed. Examples are afforded by Avens (hook = persistent style on each achene); Goosegrass; Medick (pod coiled, bearing hooks); Sanicle, Chervils, and a few other Umbellifers; Agrimony (hooks on receptacle); Enchanter's Nightshade (fig. 126). The flower-heads of Teasel and Burdock have hooked bracts; in Burweed * (*Xanthium*) the female flower-head is covered with hooked prickles and ends in two short conical beaks; and in Bur-marigold (*Bidens*) each achene has a pappus of two or three stiff bristles covered with small downward-pointing prickles. Hooks and spines often serve to protect fruits against

* A curious Composite, found in South England (not native), with small heads of unisexual flowers.

animals which might otherwise eat them; this is probably the case with the spiny capsules of Horse-chestnut, the stiff bristles (awns) of Barley, etc.

Active dispersal takes place when animals seek out fleshy fruits in order to devour them. The seeds are protected by hard stones in the case of drupes (Cherry or Plum), or by thick leathery testas in the case of most berries (Gooseberry, Red Currant), by the pericarp in aggregate fruits such as the Strawberry or the hip of the Rose. In some cases the substance of the seed is hard and quite indigestible, and in not a few cases the seed itself is poisonous. Hence in many cases the seed can pass through the animal's body without being injured, and if deposited in suitable soil may succeed in germinating. Very often, however, the hard part of the fruit is never swallowed, but allowed to fall to the ground after the soft part has been pecked; for the animals concerned in this mode of dispersal are usually birds whose gizzards may crush small seeds and destroy them. The fleshy part of the fruit is usually conspicuously coloured, and may be produced from almost any part of the flower; from the ovary-wall (Cherry), the receptacle (Apple, Strawberry), the perianth (Mulberry), etc. Sometimes the seed has a coloured fleshy *aril* or extra seed-coat—*e.g.* Spindle-tree, Yew, Nutmeg ("Mace" = aril).

Dry fruits (Acorns, etc.) may also be actively dispersed by such animals as squirrels, etc., for these animals often forget some of the hoards they lay up in autumn. This is, however, an accidental mode of dispersal, and, except in the presence of a hard pericarp, the structure of the fruit shows no special adaptations which might render this kind of dispersal more constant and profitable.

302. **Explosive Fruits.** Some fruits show active movements by which the seeds are scattered or flung out suddenly. The Squirting Cucumber has already been mentioned. In Balsams the fleshy capsules have swollen and stretched walls, so that a slight disturbance causes the capsule to burst, and the seeds are thrown a few feet away. The seeds of Wood Sorrel have a fleshy aril, which is very elastic, and when the capsule opens the aril suddenly turns

inside out and jerks the seed away. The capsule of the Violet splits into three boat-shaped parts, whose edges roll together in drying and squeeze the polished surfaces of the seeds, causing the seeds to jump away. In Geranium, the carpels split apart, and the style splits off a slender thread attached to each carpel; these threads suddenly curl upwards and outwards, so as to throw the seeds out. The ripe pods of Gorse and of Broom suddenly burst open with an audible crackling noise, the two valves becoming twisted and the seeds scattered; this can easily be observed on a warm day.

303. **Seeds.** It will be noticed that the life-history of a flowering plant which reproduces itself by seed is divided into two periods, one short and the other long. The fertilised germ proceeds as far as the production of what is usually recognisable as a young plantlet, and then stops, the further life-history of the plant not being resumed until the seed germinates. The quiescent period may be of great length, for seeds have been known to germinate after being kept dry for over fifty years, although those of other plants may perish after a few weeks. Furthermore, the difference between endospermic and non-endospermic seeds simply consists in the fact that, in the latter case, all the available food materials are absorbed and stored up in the young seed as it ripens, whereas in the former they are not absorbed until the seed germinates. In correspondence with this fact, the young embryo is usually much less developed in endospermic than it is in non-endospermic seeds.

The structure of the seed is best made out by the examination of thin sections. Rather puzzling appearances are, however, presented when the embryo is curved or twisted instead of being straight, or when the cotyledons are folded, or divided into lobes, as in Cress seeds, for in such cases the same part may be cut twice in the one section. The Brazil nut is a non-endospermic seed in which the shell is the testa. It is almost entirely filled by the axial portion of the embryo, which is swollen with food materials. The cotyledons are rudimentary, and the plumule and radicle comparatively undeveloped. The stone

of the Date is simply a seed with hard endosperm and a minute laterally placed embryo. Most Monocotyledons have a very minute plumule, usually placed to one side of a small notch occurring at the base of the large terminal cotyledon.

In some seeds special outgrowths or *arils* are formed at the point of attachment of the seed and funicle, or from the surface of the seed. These assume the form of wart-like, fleshy excrescences in the seeds of the Pansy, Castor Oil plant, and the Spurge. In the Willow and Poplar the aril is represented by a tuft of hairs which grow out from the funicle. Occasionally the aril forms an irregular fleshy investment to the seed, an example of which is afforded by the mace of Nutmegs. The succulent part of the red "berry" of the Yew is simply a special kind of aril, as is shown by its mode of development.

304. **Practical Work on Fruits and Seed-Dispersal.** Collect all kinds of fruits, belonging to both wild and cultivated plants, and arrange them according to (1) their structure, (2) their adaptations for seed-dispersal; see Appendix IV. Make sketches of all the fruits you examine; cut them across or open them up to make out the structure. Distinguish between one-seeded fruits (achenes, etc.) and true seeds, and notice which part of a fruit is fleshy, which part forms wings or tufts of hairs, etc. Carefully notice and compare the times taken for a winged or plumed fruit or seed to fall to the floor (1) with the wings or plumes still on it, (2) after removing them. Watch the scattering of flattened, winged, and plumed fruits and seeds on a windy day. Why do some winged fruits—*e.g.* Ash-"keys," Sycamore—whirl round while being blown away, and what are the advantages of this?

QUESTIONS ON CHAPTER VII.

1. Describe the changes which an ovule undergoes in becoming a seed.

2. Distinguish between syncarpous and apocarpous fruits, and give examples of common table fruits under both heads.

3. Compare carefully the flower and fruit of a Rose with those of a Buttercup, and explain, by means of diagrams, the principal differences between them.

4. Show by comparative drawings of the flower and fruit of the Apple, the Rose, the Blackberry, the Plum, and the Strawberry just what parts of the flower and fruit correspond to one another in each case.

5. Mention two plants, each of which possess a persistent calyx. Fully describe the calyx, and explain its use to the plant in both cases.

6. Describe and compare the fruits of the Rose, Fig, Strawberry, and Mulberry.

7. Give instances of seeds or fruits which are dispersed (*a*) through the agency of the wind, and (*b*) through the agency of animals. Of what advantage is it to plants that their seeds should be thus dispersed?

8. Describe examples of fruits or seeds which are dispersed by water, pointing out any adaptations for this method of dispersal.

9. Give an account of the various ways in which seeds are protected during the period of ripening.

10. What is the use of the fruit to a plant? Describe briefly with figures the characteristic fruit of *Cruciferae*, *Leguminosae*, and *Scrophulariaceae*.

11. Describe any three fruits which are adapted for dispersal by wind, explaining the nature of the adaptation in each case.

12. Describe with the help of drawings five different devices by which seeds are scattered. Describe any experiments you have made on the scattering of seeds.

13. Mention any fruits or seeds you know which are distributed by the agency of animals. Describe the structures used in five cases. Have you made any personal observations on such distribution?

14. Write a short account of the structure of the more common dry dehiscent fruits, and explain how the seeds are scattered in those examples which you describe.

15. Describe examples of explosive fruits, and try to explain the mechanism in each case.

CHAPTER VIII.

NUTRITION, GROWTH, IRRITABILITY.

305. We have now acquired some knowledge of the life-processes of plants as far as their nutrition, growth, and responses to external stimuli are concerned. In this chapter we may summarise and add to this stock of knowledge, and at the same time consider the methods by which some plants obtain food from other sources than the water, mineral salts, and carbon dioxide which suffice for the nutrition of the normal green plant growing in light and air.

306. **How Photosynthesis was Discovered.** Until nearly the middle of the seventeenth century, it was believed that plants receive all their food in a state ready for use—that is, that the soil formed a kind of stomach which prepared food for plants, so that the latter had merely to absorb this food, and had nothing to do with making food for itself. About 1630, however, **Van Helmont** made an historic experiment, the first ever made in plant physiology, so far as we know. His great idea was that all things consist largely or almost entirely of water, *hence he argued that the whole of a plant* is formed from water. He thoroughly dried some soil, and placed 200 lb. of the dry soil into a pot, and then planted in it a Willow branch which weighed 5 lb. He watered the soil daily with rain-water for five years; the Willow had by then grown into a large and vigorous plant. The Willow now weighed 169 lb., but the soil in the pot, on being dried, showed a loss in weight of only 2 oz. Van Helmont concluded that the increase in weight of the plant had been gained entirely from the water, and that all the substance of the plant is formed from water. In 1671 **Malpighi**, one of the earliest workers on the minute structure of plants, tried to explain the functions of the different organs of

plants, basing his theory of nutrition chiefly on *structure.* He thought the fibres in a stem conveyed water upwards from the roots, while the vessels carried air. He could not find any openings on either roots or leaves for the entrance of air, but thought it must enter by the roots, because the latter contain vessels, and because air tends to rise upwards. He found that the plumule of a very young seedling will not grow if the cotyledons are removed, hence he concluded that in the cotyledons (and, by analogy, in all leaves) the crude sap brought from the root is elaborated to form nutritive sap, which then passes to other parts of the plant. **Mariotte** in 1679 argued, from common observation and from the facts of chemistry known at that time, against the absurd view that had already been disproved by Van Helmont. His argument was that if all the substances, and even the tastes and odours of plants, are all ready prepared in the soil (according to the old view), and yet a small amount of soil can be used to grow all kinds of different plants in, then all the different salts, oils, and other substances found in the plants must have been present in the few ounces of soil at whose expense, along with rain-water, these different plants grew. He showed that this was impossible, and that plants change their raw food-materials, by chemical processes, into new substances; also that the soil and the water supply to the most diverse kinds of plants the same raw materials. In 1727 appeared the famous "Statical Essays" of **Stephen Hales,** who experimented chiefly on the absorption of water by roots and its evaporation from leaves. He first described clearly the passage of water into, through, and out of the plant, measured the rate of the transpiration-current and the forces of suction (negative pressure) and of root-pressure. He dealt chiefly with transpiration, but he also showed, by using the air-pump, that air circulates in the plant, entering by the leaves and also by openings in the bark. He found that gases are driven off in large volume when plants are strongly heated, and this led him to suggest that air in some way contributes to the nutrition of plants. However, it was not shown until long after Hales' time that the green leaves actually take up a constituent of the atmosphere, and use it in making organic

food. The discovery of this remarkable fact was closely connected with the researches of **Priestley, Cavendish,** and **Lavoisier,** who laid the foundations of modern chemistry. In 1779 **Priestley**, who had discovered oxygen gas a few years before, noticed that green plants give out oxygen, but he did not go deeply into the matter. In the same year, however, **Ingenhouss** showed that this giving-out of oxygen only occurs in light, and that in the dark plants give out carbon dioxide (whose properties had been studied long before this by Joseph Black). Ingenhouss further showed that the parts of plants which are not green give out carbon dioxide both in light and darkness. In his books, *Experiments on Vegetables, discovering their great power of purifying the common air in the sunshine and of injuring it in the shade and at night* (1779), and *On the nutrition of plants and the fruitfulness of the earth* (1798), he clearly distinguished between (1) the absorption of carbon dioxide for nutrition and (2) the process of respiration, and showed that while all parts of plants continually give off carbon dioxide, the green leaves only give off oxygen in the light, also that the carbon in the plant comes from the air and not from the soil. The work of **De Saussure** (1804), who applied the chemical knowledge and methods of experiment then available, led him to two great discoveries, (1) that the elements of water are fixed in plants when they fix carbon from carbon dioxide; (2) that plants require nitrates and other mineral salts. Not until after 1860, however, was it known that carbohydrates are formed in the leaf as the result of photosynthesis. Even now we are not certain about the exact stages in the process which results in the appearance of starch-grains in the chloroplasts, as the first visible product of assimilation. In some plants starch is not formed, the products of assimilation being sugars, organic acids, oils (in some Algae), etc.

307. **Parasites and Saprophytes.** So far we have dealt only with the manufacture of food by photosynthesis, the raw materials being water (containing dissolved earth-salts) and carbon dioxide, and the energy required for this process being derived from sunlight by means of chlorophyll.

Some plants obtain their food in a totally different way, by living as *parasites* on other living plants (or on living animals in the case of some bacteria), or as *saprophytes* on dead organic matter. Parasites and saprophytes are distinguished as *total* or *partial*, according to whether they get the whole, or part only, of their food in these ways. Plants which have no chlorophyll are necessarily total parasites or saprophytes, since they cannot use free carbon dioxide, and must obtain carbon in the form of organic compounds. Fungi and bacteria can usually obtain the nitrogenous part of their food from fairly simple nitrogen compounds—*e.g.* salts of ammonia—and some of them can fix the free nitrogen of the air, but for their carbon all chlorophyll-less plants appear to be dependent on the organic substances manufactured by plants which have chlorophyll.

308. **Total Parasites.** Dodder, Broomrape, and Toothwort are British examples of flowering plants which are practically total parasites. The seedling of the Dodder sends its radicle into the ground, while its shoot grows greatly in length, and at the same time sweeps around in widening circles in the air. If it meets with a suitable plant (the plant on which a parasite grows is called, rather ironically, its *host*), such as Gorse, Thyme, Clover, or Heather, the Dodder-stem twines round the host-plant, and sends into it root-like organs which eat their way to the bundles, then the vessels in these organs fuse with the vessels of the host-plant, and the same happens with the sieve-tubes. In this way, the Dodder taps both the wood and bast of the host-plant, from which it draws organic food as well as water and salts. Meanwhile the radicle of the Dodder dies off. If the Dodder seedling does not happen to meet with a host-plant, it soon dies. The Dodder has very small scales instead of ordinary green leaves (why?), but it produces enormous numbers of clustered flowers (why?). The Broomrapes are root-parasites—*i.e.* their roots are attached to, and absorb both inorganic and organic food from, the roots of other plants. The commonest British species are the Great Broomrape (*Orobanche major*) which grows chiefly on the roots of Broom and Gorse, and the Lesser Broomrape

which grows on various plants. Rarer species are the Blue Broomrape (*O. caerulea*), which grows almost solely on Milfoil, and the clove-scented Broomrape (*O. caryophyllacea*), said to be restricted to Bedstraws. The Toothwort (*Lathraea*) has a creeping underground stem (rhizome) bearing crowded fleshy leaves which are hollow and probably serve to excrete excess of water absorbed from the host-plant, and erect stems bearing flat scales and ending in a spike of flowers. The Toothwort grows chiefly on the roots of Hazel, into which it sends parasitic roots, and is found in woods. All these plants are almost or quite devoid of chlorophyll. The hollow leaves on the underground shoots of Toothwort have been regarded as traps for insects, which were supposed to be held fast and digested by the glands lining the branching cavity in each of these leaves, but this has not been proved.

309. **Partial Parasites** are plants which contain chlorophyll and have ordinary foliage-leaves, so that they can make at least part of their organic food by photosynthesis, while they draw their supply of water and dissolved salts from a host-plant. When the seed of the Mistletoe (whose sticky fruits are carried by the birds) germinates on the branch of a suitable tree (Apple, Oak, Hawthorn, etc.), the radicle penetrates the host, and the woody tissues of the two plants become continuous (fig. 180). Several members of the Foxglove family (*Scrophulariaceae*) are partial parasites, their roots being attached to the roots of other plants, chiefly grasses, though (like the mistletoe) the plant has green leaves which carry on photosynthesis. Examples are the Yellow Rattle, Lousewort, Eyebright, Cow-wheat, and *Bartsia*. Most of these plants grow in swampy grass-fields, and where their

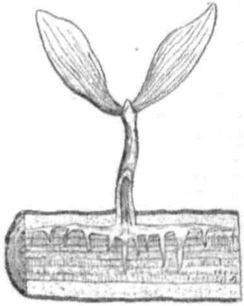

Fig. 180.—Young Mistletoe Plant, with Twig of Host-plant in Section.

roots come into contact with the roots of grasses, swellings (suckers) are formed, from which parasitic roots grow into the grass-roots. The suckers are formed in spring, and through the summer they absorb food from the living grass-roots; during this time they contain little or no starch. In late summer and autumn organic food is absorbed from the dead grass-roots, and the suckers then store reserve food. Lousewort and *Bartsia* can grow even when unable to attack the roots of other plants, but this apparently does not apply to the other types.

310. **Total Saprophytes.** British examples of totally saprophytic flowering plants are the Bird's-nest (*Monotropa*) and the Bird's-nest Orchid (*Neottia*), both found in thick leaf-mould (humus) of woods. Both plants have the lower part of the stem covered with a mass of short, thick roots (hence the name "Bird's-nest"), and the fleshy upper part of the stem, ending in a raceme of flowers, bears small yellowish-brown scales instead of green leaves. *Monotropa* belongs to the Heather family (Ericaceae), while *Neottia* is allied to the Twayblade Orchid (*Listera*). In both cases the plant is unable to grow in soil which contains no organic matter, and it is enabled to make use of this matter for nutrition by the help of a "fungus-servant." Some of the fungus-threads which permeate the leaf-mould form a dense matting on the surface of the roots of *Monotropa*, and in *Neottia* these threads penetrate the roots and actually grow inside the living cells of the cortex. In this way the higher plant is supplied with digested and soluble organic food which it could not absorb in the ordinary way by means of root-hairs. In these two plants it appears that the whole of the food is obtained by the aid of the fungus-threads, and since the fungus by its association with the roots also gains certain advantages—*e.g.* shelter from drought—the arrangement is an example of a mutually helpful partnership or *symbiosis* (living together). This particular kind of symbiosis is called a *mycorhiza*—*i.e.* an association of a fungus with the roots of a higher plant.

There is no dividing line between total and partial saprophytes; even *Neottia* has some chlorophyll.

311. **Partial Saprophytes** also have a mycorhiza on their roots, but since they have green leaves, and therefore carry on photosynthesis, the higher plant is not so completely dependent on its fungus-servant. The roots of most forest-trees, and of many other plants which grow in the rich humus of woods and plantations, have an external mycorhiza like that of *Monotropa*, while in Ericaceae (Ling, Heather, Bilberry, etc.) the mycorhiza is usually internal as in *Neottia*. Most of the plants growing in the peaty soil of heaths and moors have mycorhizas; this is the case, for instance, with moorland grasses, though apparently not with Sedges and Rushes which grow in the wetter boggy parts. In the case of partial saprophytes, it is probable that the free fungus-threads which project from the surface act as root-hairs, and absorb water and inorganic salts in addition to organic compounds. The latter are probably chiefly absorbed for the sake of the nitrogen they contain, since the green plants can absorb carbon dioxide from the air. Plants provided with a mycorhiza produce few or no root-hairs, since the projecting fungus-threads form a far more effective means of absorbing food-materials than do root-hairs. See pp. 391–5.

312. **Leguminous Root-Nodules.** It has been known for many centuries that crops of Clover, Lupin, Beans, or other leguminous plants actually enrich the soil in which they are grown.* This fact is mentioned in Virgil's *Georgics*, but the explanation of it was only arrived at a few years ago. It has long been known that the roots of Leguminosae often bear peculiar swellings,† which in some cases (*e.g.* Broad Bean) are as large as hazel-nuts. Various observers, from Malpighi onwards, have written about them, and various views have been held regarding their mode of formation and

* For this reason leguminous crops are often grown as "green manure" and ploughed into the soil.

† Nodules occur on the roots of various other plants—*e.g.* Alder, certain Sedges and Rushes, Broomrape, and in these cases the nodules are formed by Fungi, whose threads branch in the cells of the nodule. Other swellings, occasionally found on roots, are produced by thread-worms and by insects; these are of similar nature to the "galls" found on the shoots and leaves of various plants.

their biology. Apparently the nodule begins as a swelling of the cortex of the main root or a rootlet, and at first the cells contain only fungus-threads, which enter by means of the root-hairs. The nodule is evidently produced as the result of the entrance of the Fungus from outside, the Fungus setting up a stimulus to active growth of the cortex-cells. Later, the nodule becomes lobed and its outer cells become flattened, forming a sheath which contains vascular bundles. The Fungus-threads in the cells of the nodule branch profusely and give off numerous buds, as in the growth of the Yeast-plants; these minute bodies have been taken for Bacteria, and have been called "bacteroids." In annuals the nodules become emptied as the seeds ripen. Analyses show that the nodules are very rich in nitrogenous substances, also in potash and phosphorus, and they seem to develop best in soils which are poor in nitrogen compounds. The nodules do not develop in plants grown in garden or field soil which has been heated so as to kill any organisms present in it. On the other hand, they grow on roots of plants which have been germinated in garden soil and then placed in culture solution. There seems little doubt that the Fungus lives in symbiosis with the roots of the Broad Bean, and it probably fixes the free nitrogen of the air present in the soil, just as some of the true Bacteria do. The "bacteroids" budded off by the fungus-threads are no doubt widely distributed in the soil, ready to germinate and send threads into the roots of Bean and other Leguminosae. The arrangement is evidently a special kind of mycorhiza, the "bacteroids" supplying the leguminous plant with nitrates (made by them from free nitrogen), while they are supplied with sugar manufactured by the host-plant. The case is evidently one of modified parasitism on the part of the Fungus, which sets up active growth in the root of the host-plant, just as galls are produced by insect-bites, but is kept in check and used by the host-plant to aid in its nutrition. This peculiar symbiosis between the "bacteroid"-forming Fungus and the roots of leguminous plants explains why the latter can flourish in soil containing little combined nitrogen and actually leave the soil rich in nitrogen-compounds after they have grown in it.

313. **Carnivorous or Insectivorous Plants** obtain part of their nitrogenous food by catching insects in various ways, by means of modified leaves, and afterwards absorbing the soft parts of the insects. The British insectivorous plants are the Sundews, Butterwort, and Bladderwort. The Butterwort has a basal rosette of broad leaves, whose upper surfaces are covered with sticky glands, while the margins are rolled inwards slightly. Small insects are caught by the sticky liquid and washed by rain to the edge of the leaf, which curls inwards and encloses them; the glands then secrete digestive ferments, absorb the products, and then the leaf becomes unrolled again.

The leaves of Sundew bear numerous stalked glands or tentacles which secrete a sticky fluid (fig. 181). If an insect adheres to the tentacles, they bend down upon it and pour out a fluid which has the power of digesting, and rendering soluble, albuminous or proteid substances (white of egg, meat, etc.) in a similar manner to that occurring in the stomach of an animal. The secreted fluid is reabsorbed, together with the soluble nitrogenous products (peptones). When digestion is completed, the tentacles resume their former position, and are then ready to capture another insect, a process which may be repeated several times. The tentacles may be stimulated to movement by continued contact with any solid substance, but apparently no digestive fluid is secreted unless a suitable organic substance—*e.g.* a piece of raw meat or of boiled egg-albumen—is placed on the leaf.

Fig. 181.—Leaf of Sundew. Tentacles expanded on the right; partially inflexed over an insect on the left.

The Bladderwort is a submerged water-plant which has no roots; the submerged parts show no clear division into leaves and branches, but are finely divided, and the flowering shoots project above the water. The submerged parts bear curious bladders, each with a trap-door or valve which is easily opened by a push from the outside, so that small animals (insects, water-mites, water-fleas, etc.) cannot

escape once they have entered the bladder. When these animals die, their soft parts decay and are absorbed by branched hairs which occur on the inner surface of the bladder.

The leaves of Venus' Fly-trap * are two-lobed, and the midrib acts as a hinge. Each lobe bears on its upper surface three long sensitive hairs, and when one of these hairs is touched, the two lobes snap together, just as one closes an open book, and capture the insect that has caused the disturbance (fig. 182). Digestion occurs as in Sundew. The leaves of Venus' Fly-trap are only slightly sensitive to chemical stimuli, but if the closing of the lobes has been

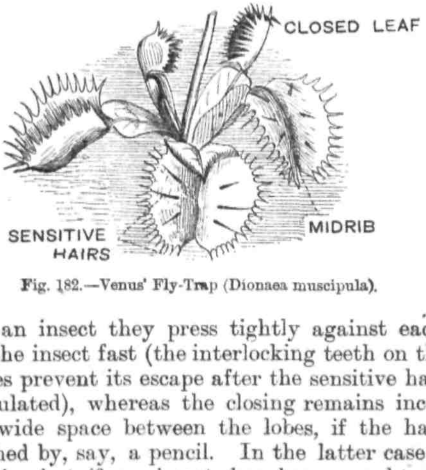

Fig. 182.—Venus' Fly-Trap (Dionaea muscipula).

caused by an insect they press tightly against each other and hold the insect fast (the interlocking teeth on the edges of the lobes prevent its escape after the sensitive hairs have been stimulated), whereas the closing remains incomplete, leaving a wide space between the lobes, if the hairs have been touched by, say, a pencil. In the latter case the leaf opens again, but if an insect has been caught the leaf remains closed until the digested products have been absorbed.

In the Pitcher-plants, of which *Nepenthes* (fig. 183) is the best-known example, the whole or a part of a leaf is developed as a pitcher with a lid attached to one side of the

* A native of Carolina, where it grows in swamps; often cultivated in hot-houses.

opening. The bottom of the pitcher contains water, usually swarming with Bacteria, and in *Nepenthes* a digestive ferment (pepsin) is secreted, so that the insects falling into this liquid are first drowned and then digested. The pitchers of *Sarracenia* (fig. 184) are also modified leaves, but instead of digesting the captured insects they seem simply to absorb the products of their decomposition by Bacteria. In these and other Pitcher-plants, the lids of the pitchers are brightly coloured and serve to attract insects, but they have no power of movement, and cannot close when once

Fig. 183.—Pitcher of Nepenthes Distillatoria.

Fig. 184.—Pitcher of Sarracenia.

they have opened. The rim of the pitcher also bears honey-glands, which help in attracting insects; below the rim there comes a zone covered with small glands sunk in pits on the inner surface of the pitcher, then comes a smooth slippery region, the lower part of which has hairs pointing downwards, and finally the lowest part containing water. Insects crawling over the gland-bearing upper region soon reach the slippery zone, and are prevented by the hairs below this from crawling up again, so that they eventually fall into the liquid and are drowned.

Most insectivorous plants have enough chlorophyll to enable them to make all the organic food they need, and

is not merely an increase in size, but a permanent change in form owing to the formation of new substance. In some cases we can recognise a temporary increase in size without growth taking place, as when cells become turgid. Growth takes place in all directions of space, but in most cases there is one direction along which the growth of an organ is most active. When growth begins in any part, it proceeds slowly at first, but gradually quickens until it reaches its greatest rate, after which it slows down until the energy of growth is exhausted and the part acquires its permanent form.

Very often the parts of an organ do not grow at the same rate at the same time. One side of the plumule of a Broad Bean seedling grows at first much faster than the other side; this causes the bent form in which the young shoot reaches the ground. The lower side then enters on its rapid period of growth, so that the young shoot becomes straightened. The folding of leaves in the bud is due to the same kind of growth.

316. **Properties of Growing-Points.** At the tips of stems and roots the growth is greatest, not at the point where there is most rapid division of cells, but at some distance behind this point—that is, the formation of new cells is most abundant at the growing-point itself, but the growth and increase in size of the cells take place chiefly at some distance behind. We have seen that the free end of a root shows several distinct regions, easily recognised: (1) the growing-point, covered by the root-cap; (2) elongating or growing region; (3) region bearing root-hairs; (4) thickening region, where also rootlets are produced. The growth of a bud while it is unfolding affords another example. In the bud the internodes are extremely short. Rapid elongation takes place when the bud begins to unfold. In some cases growth may continue for a long time in the internodes, although they are far removed from the apical meristem. Similarly, the rapid growth of the leaf is effected when unfolding, although all the cells of the leaf are present in the bud-condition.

The elongation of the growing-point (stem or root) is not

in a straight line. As it elongates the growing-point may move from side to side in a zig-zag course, or describe a spiral. The reason is that growth is not equal all round the growing-point. If the growth is more rapid, first on one side and then on the other, the zig-zag movement is produced. The spiral movement is due to a wave of more rapid growth passing round the growing apex. This movement is called **nutation.**

The cells at growing-points are always **turgid.** There is a rapid osmosis of nutritive substances into the cells. This is always the case where metabolic processes are actively going on. The metabolic processes disturb the general equilibrium as regards the distribution of nutritive substance, and at the same time lead to the formation of osmotically active substances. Hence water with nutritive substances in solution are drawn into these cells from neighbouring cells. Turgidity is an essential condition of growth; turgidity brings about temporary changes in form which are rendered permanent by the formation of new substance.

Considering this condition of turgidity, it is evident that there must be considerable pressure (or tension) in the tissues at growing-points. When the epidermis is being formed as a firm and rather inextensible membrane it will be stretched to some extent by the growing cells within, and these again will be compressed owing to the inextensible nature of the epidermis. In other words, the pith, for example, tends to expand, but is prevented by the outer tissues. Thus there is a considerable transverse tension in a stem. This is easily demonstrated by a simple experiment. Cut the growing apical region of a stem longitudinally into two halves; the two halves bend away from each other. This is due to the expansion of the pith, which will be found to present a convex surface. Again, remove a complete ring of outer tissue from a stem; on trying to replace it, it will be found that it does not go quite round owing to the expansion of the inner tissue. In stems and roots there are also longitudinal pressures or tensions, but these are not nearly so considerable as those in the transverse direction.

317. **Irritability** is one of the fundamental properties of protoplasm; in other words, it belongs to the nature of living protoplasmic substance that it is capable of receiving impressions from, *i.e.* of being stimulated by, various external influences, and of making certain responses to these stimuli. The consideration of this fundamental property opens up the whole question of the plant's relation to its environment. It is this property which brings the organism "into touch" with its surroundings. On it ultimately depends the harmony which is everywhere exhibited between a plant and its environment. The mature organs of plants, in many cases, make responses to the action of external stimuli, but such responses are best exhibited by the *growing* organs. In growth the vital activity of the protoplasm is constantly subjected to, and modified by, the stimulating influence of external agencies.

The response may occur at a distance from the point stimulated, as is illustrated by an electrical bell connected by wires to the bell-push, which, when pressed inwards, completes the circuit and sets the bell ringing. In this case only one stimulus (pressure) can act, the response is always the same, and the mechanism is comparatively simple. In plants, however, the irritable mechanism is extremely complex, and is such as to be able to respond to any stimulus, if sufficiently intense. Moreover, the response produced depends upon the character of the organ or plant affected, as well as upon the nature of the stimulus. Thus the same stimulus, gravity, causes the primary root to grow downwards, the stem upwards, and the lateral roots, as well as certain rhizomic stems, horizontally. Again, most stems respond to light by growing towards the source of illumination, whereas most leaves and a few stems develop so as to place themselves at right angles or obliquely to the direction of the light.

Many leaves droop or become more vertical in position at night, the leaflets of Clover and Wood-Sorrel fold together in darkness, the flower of the Red Campion closes at night-time, as also do the inflorescences of the Daisy and Dandelion. The times of opening and closing vary in different flowers, and hence it is possible to construct

a kind of floral clock by arranging flowering plants in series in a circular bed, according to the times their flowers either open or close.

Other flowers, however, such as those of the Sweet-scented Tobacco and the Evening Campion (*Lychnis vespertina*), close when exposed to bright light, and open in the dusk of the evening. In the latter case this is because the flowers are fertilised by night-flying moths, and hence economise their odour and nectar during the day. At the same time, in the closed position of the flower (or inflorescence), the essential organs are protected from marauding insects, and from various injurious external influences. The opening of such flowers as those of the Tulip or Crocus is produced by a rise of temperature, as occurs, for example, when the sun is shining upon them. When the temperature falls, the perianth leaves fold together again. The movement is due to the fact that above a certain temperature the inner surfaces of the perianth leaves grow more rapidly than the outer, so that the leaves spread apart. At temperatures approaching the freezing-point of water the reverse effect is produced, the leaves slowly fold together, causing the flower to close, and thus to a large extent protecting the essential organs from the effects of frost. The opening movement is usually more rapid than the closing one, owing to the fact that growth in general is more rapid when the plant is moderately warm than when it is cold.

Other instances of special irritability are afforded by tendrils which respond to contact by curving, and by the stalks of developing fruits, as well as the hooks and tendrils of shrubby climbers, which respond to increased tension and strain by becoming thicker and stronger. Here the stimulus influences growth, and such slow movements as are involved in geotropic and heliotropic curvatures are the result of unequal growth, and hence are only possible in organs which have not lost this power.

The rapid movements of leaves and leaflets are produced by the motile organs, *pulvini*, at their bases. The cells of these organs absorb water on one side and swell, while those on the other lose water and collapse, so that the pulvinus, and with it the leaf, bends towards the latter side.

318. **Relation between Strength of Stimulus and Response.** If a stimulus is steadily increased in strength, the response usually becomes more and more pronounced, until a certain limit is reached, beyond which the response may either diminish again or change in character. Thus in darkness the leaflets of the Sensitive Plant fold together in pairs and the leaves droop downwards. In diffuse daylight the leaves rise upwards, and the leaflets become expanded horizontally. If the light steadily increases the leaflets begin to rise up in pairs, and in strong sunlight they fold completely together. Similarly the leaflets of *Oxalis*, and of many tropical plants which fold together, droop downwards or rise upwards in darkness, expand horizontally in diffuse light, and turn their edges to the sun when it is shining upon them. Many free-swimming microscopic plants move towards the light when it is feeble, but away from it when intense. In this way these plants, and the leaves mentioned, shield themselves from injury by intense light.

319. **Constant Stimuli.** Certain conditions, such as a suitable temperature, a supply of oxygen and water, and usually also frequent exposure to light are essential for the development of a flowering plant. Most green plants, for example, have become so accustomed to daily exposure to light, that they fall ill and ultimately die when grown in darkness, even though fully supplied with food. In this case the stimulus of light is a recurrent one, but under normal conditions the influence of water, oxygen, and temperature may be kept approximately constant. These three factors then co-operate with the living protoplasm in producing a continuous response—namely, **growth**. In addition a special stimulating effect becomes perceptible when any one of these factors is diminished or increased. This is shown when cold weather hastens the fall of the autumn leaves, or when a deficiency of water in summer-time causes many of them to be thrown off, or when the absence of oxygen prevents the development of roots in badly aerated soil.

320. **The Influence of the External Conditions on Irritability.** Flowering plants only respond to stimuli when certain conditions are fulfilled. These are (1) a supply of food, water, and oxygen, (2) a sufficient temperature. Again, an unhealthy plant, one grown in darkness for example, or in the absence of iron or potassium, may respond feebly or not at all to stimuli which affect it strongly when healthy. Plants, like animals, may be rendered temporarily non-irritable—that is, more or less incapable of responding to stimuli—by means of chloroform or ether. In both cases if the doses are too severe, death may ensue, and in fact, as regards irritability, the difference between plants and animals is only one of degree.

QUESTIONS ON CHAPTER VIII.

1. How, and by whom, was it first proved that a green plant does not get all its food from the soil?

2. How, and by whom, was it first proved that green plants make food from a constituent of the atmosphere?

3. Describe the chief characters of British flowering plants which are total parasites or total saprophytes.

4. What is there peculiar about the nutrition of leguminous plants? Explain the importance of Leguminosae in the rotation of crops.

5. Mention three carnivorous plants that occur in Britain, and describe the structures that are adapted for catching or trapping the animals in each case.

6. What is growth, and on what conditions does it depend? Describe the phases of growth at the tip of a root or a shoot.

7. What changes in the composition of the air are brought about (1) by green plants, (2) by animals? At what stage of its life does a plant behave in this respect like an animal? Explain the phrase "balance of nature."

8. What is meant by the *irritability* of plants? Illustrate your answer by reference to growing stems and roots.

9. Carefully define what you mean by *reaction to stimulus*, as applied to plants. Describe fully three cases of such reaction which you yourself have observed.

CHAPTER IX.

THE ECOLOGY OF PLANTS.

321. **Plant Ecology**. Having now gained some practical knowledge of the structure and life-processes of plants, you should proceed to study the vegetation of your own district and that of any district you may visit. The main object of this study should be to find out as much as possible about the various ways in which plants are influenced by, and adapted to, their surroundings or "environment." The term **Plant Ecology** simply means "the study of plants in their homes." Much can be done in this direction even with limited knowledge of the classification of plants; but the more you know of structure, physiology, and classification, the better will you be equipped for the study of plants from the ecological point of view. It is an easy task to learn how to distinguish the commoner plants, especially those which show striking adaptations to some special locality or "habitat." There are various books which enable one to identify any flowering plant met with in this country. The most complete of these "Floras" are Bentham and Hooker's *British Flora*, and Hooker's *Student's Flora*; the former is illustrated, and is the more expensive of the two. Smaller books, less complete and less expensive, are Hayward's *Pocket Flora* and Watts's *School Flora*. A still cheaper, but extremely useful, Flora is Fox's *How to find and name Wild Flowers* (Cassell, 1*s*. 6*d*.), which may be recommended to beginners in the work of plant identification. The summary of the chief Orders which is given in our Appendix III., together with the monthly lists of plants in flower (Appendix IV.), will probably be useful.

Since Plant Ecology and Classification are naturally studied together in outdoor work, and both are closely connected with the Evolution of plants and with their Geographical Distribution, it is necessary to consider these subjects briefly.

322. **Evolution.** The study of plants and of animals has led to the conclusion that all the types that exist at present, as well as those which formerly existed, have arisen from a common ancestor, by the process of Evolution. Evolution may be described as the gradual response of successive generations to their environment, using the latter term in the widest sense. Evolution is the result of the inter-action of the following factors:

(1) Competition, or Struggle for Existence	= indirect influence of the environment.
(2) Survival of the Fittest	

(3) Variation.
(4) Heredity.
(5) Direct influence of the environment.

Consider how numerous are the seeds produced by any one plant, and then reflect that the number of individuals in any one species remains approximately the same from one year to another. Evidently very few of the seeds develop into mature plants. Some fail to reach a suitable soil; others produce seedlings which, however, are crowded out and killed by other and hardier plants—and so on.

Every warm, moist, uncultivated region of the earth's surface, where the soil is moderately fertile, is overcrowded with plants, and the constant production of numerous seeds tends to still further increase the crowding. Whenever the competition becomes so keen, only the fittest can survive, and it is clear that the external conditions will determine which are the fittest, and that the character and number of the different competitors will determine which shall survive in the struggle for existence.

In each generation the influence of the external conditions, by killing off the weaklings, *selects*, as it were, those which by reason of some useful variation are more fitted for survival, just as a gardener might select the plants showing the variation which he wishes to intensify. The sum-total of external conditions constitutes what we call "*Nature*," and therefore to this operative cause the name "*natural selection*" has been appropriately given.

Very frequently plants that fail in open competition are

able to exist in special localities owing to their having acquired some special adaptive modification. For example, the plants growing in sandy places close to the margin of the sea are able to exist on a small supply of water, and are not injured even when the water is distinctly brackish and contains a large quantity of salt. It is well known that the characters of parents are transmitted to their offspring, so that the offspring resemble their parents more or less closely. This is the principle of *heredity*.

Now, if the offspring were exact copies of their parents, and all *equally vigorous*, it would be a matter of *chance* which of them survived in the struggle for existence; those would survive which *happened* to be most favourably situated. But the offspring are not exact copies of the parents. As we know, they exhibit individual differences, some of which may appear for the first time in the history of the race. These characters in which offspring differ from their ancestors are called *variations*.

Variation—*i.e.* the fact that these variations do occur—introduces a new factor into the struggle for existence. Survival is not to the same extent a matter of chance. Some of the variations exhibited by plants may be useful or advantageous—*i.e.* they may give the individuals possessing them an advantage over other individuals in the struggle for existence. Evidently those variations will be such as will enable the individual to cope better with the external conditions to which it is subjected. Thus in the struggle for existence the fittest will survive, and their advantageous variations will tend to be transmitted, perpetuated, and even intensified in their offspring.

Thus, in the evolution of plants, new characters would arise as small useful variations preserved by natural selection and intensified in the course of generations. These characters would be suited to the environment of the plant—in other words, they would be adaptive characters, otherwise they would not have been preserved by natural selection. The student will now have a clearer idea of the origin and significance of adaptation.

The structural characters of a plant are adaptive, because they are the characters which, being useful, have

been *selected*, and have determined the existence of the plant.

Under changing conditions of environment, species which are incapable of appropriate adaptive variation tend to become extinct.

In this connection it is of importance to remember that the plant "fittest to survive" has not necessarily any utility to man, but is simply the one best suited to the existing conditions. This is well illustrated by the rapid growth of weeds in an uncultivated garden, and the extinction of all the weaker original inhabitants. Annual weeds first gain the upper hand when cultivated ground runs wild, but these are gradually displaced by herbaceous perennials, and ultimately shrubs or even trees may take possession of the soil.

Exp. 362. Plant the seeds of any common annual close together. Notice how some of the seedlings overtop the rest and conquer in the struggle for existence.

Exp. 363. Plant the seeds of Sunflowers, Field Poppies, and Scarlet Runners close together, and see which comes off best in the struggle for light.

Exp. 364. On a piece of cleared ground note the order of appearance of weeds: first year, annuals mainly appear (*e.g.* Poppies, Chickweed, Goosefoot, Shepherd's Purse, Groundsel, Speedwell, Spurrey, Scarlet Pimpernel); second and third year they are replaced by perennials (*e.g.* Nettles, Docks, Thistles, Dandelion, Milfoil, Brambles, coarse grasses, such as Couch-grass and Cock's-foot).

323. **Classification (Varieties, Species, Genera, Orders, Cohorts).** In most cases variation is **continuous**—*i.e.* the varying forms are connected by intermediate stages; but in many cases it is **discontinuous**—*i.e.* we find on examining a large number of individuals that the **varieties** group themselves in two or more sets or races hardly, if at all, connected by intermediate forms. For example, there are two common varieties of Meadow Buttercup (*Ranunculus acris*): in one (var. *vulgatus*), the stem is densely hairy at the base, and the segments of the "radical" leaves overlap each other; in the other variety (var. *Steveni*), the stem is only slightly hairy, and the leaf-segments do not overlap. Many examples of varieties are found in cultivated plants. **Varieties differ from each other in small and variable**

characters, chiefly affecting the vegetative organs, but sometimes in floral characters of slight importance—*e.g.* shape, colour, etc., of petals. **Species** differ in **more important and more constant characters** of the vegetative organs, or of the flowers and fruits, or both.

The three commonest species of Buttercup agree in many respects—*e.g.* in having five sepals and five petals, etc.—but are distinguished by the following, amongst other, characters :

	Bulbous Buttercup (*Ranunculus bulbosus*).	Meadow Buttercup (*Ranunculus acris*).	Creeping Buttercup (*Ranunculus repens*).
Stem.	Swollen at base, for storage of food.	Not swollen at base; no runners.	Gives off runners, which root at nodes, producing new plants.
Flower-stalk.	Rounded.	Rounded.	Furrowed.
Sepals.	Reflexed, *i.e.* bent downwards.	Spreading.	Spreading.

Other common species of Ranunculus are: *R. ficaria* (Lesser Celandine), with kidney-shaped leaves, tuberous roots, three sepals, eight or nine petals; *R. flammula* (Spearwort), in marshy places, with lanceolate leaves; *R. aquatilis* (Water Crowfoot), in slow streams, with floating stems, bearing (as a rule) two kinds of leaves (broad floating leaves, only slightly lobed, and submerged leaves divided into numerous fine segments). There are many varieties of *R. aquatilis*, differing chiefly in the forms of the leaves, and many botanists regard these as distinct species.

When the differences become still more pronounced and more constant, we agree to recognise distinct genera, and a number of closely related genera constitute a Natural Order. Thus the Buttercups, Anemones, Marsh Marigolds, Aconites, Paeonies, and Larkspurs all belong to different genera of the Natural Order **Ranunculaceae.**

Natural Orders differ from one another in having different types of flowers and different arrangements of the flowers and leaves. Families or orders are grouped into Cohorts. The cohorts of seed-plants fall into four great divisions:

Gymnosperms, Monocotyledons, Lower Dicotyledons (*Archichlamydeae*), and Higher Dicotyledons (*Sympetalae*), the three latter divisions forming the Angiosperms. As you proceed with the work of classifying plants, you will realise that the boundaries between varieties and species, between species and genera, and so on, cannot be precisely and sharply defined; the same applies even to the boundary between the lowest plants and animals. This is, of course, just what one might expect from what has been said about variation and evolution. Hence an absolutely natural system of classification can only be an ideal to be aimed at. The nearest approach to such a classification of Angiosperms is that of Engler and Prantl, adopted in Appendix III., which should be compared with the Bentham-Hooker arrangement given in British Floras.

324. **Evidence** in support of the evolutionary theory is derived from many sources, the chief of which are (1) the facts of development and morphology, (2) the influence of cultivation and artificial selection, (3) the discovery of fossil forms bridging over the gaps between existing ones, (4) the distribution of plants on the surface of the earth.

Development a Guide to Descent. As regards the first of these a few instances must suffice. Thus plants with compound leaves, or plants with cladodes, phyllodes, or spines have always been derived from others with ordinary simple leaves. Hence it is usually the case that the seedling bears normal foliage leaves at first, whereas later either compound leaves are formed, or phyllodes, spines, or cladodes. For example, the seedlings of *Phaseolus* (Kidney Bean) bear at first a pair of simple foliage leaves (Fig. 82), but all the subsequent ones are compound. Similarly Gorse seedlings bear first a pair of simple leaves, then a few compound ones, but all the subsequent leaves grow into hard sharp spines which represent the leaves in the adult plant. This clearly suggests the mode of development of the special peculiarity, and the early history of the particular species is in each case repeated more or less exactly during the life of the individual.

Cultivation and Artificial Selection. It is matter of common knowledge that many new varieties of plants have been produced by prolonged cultivation, and by the continual selection of the best seed, or of a particular kind of seed. Gardeners also often propagate accidental variations or "sports" by cutting or by grafting. Their attention is, however, usually directed towards producing showy flowers or fleshy fruits, points which are of little importance in classification. Hence new "species" are rarely produced by horticultural means. All the different kinds of cultivated Wheat

appear, however, to be derived from a common ancestor, although they are now recognised as forming at least five botanical species. Similarly the Almond and the Peach are different species of the same genus (*Amygdalus*), but are undoubtedly originally derived from the same plant.

An interesting example of the effects of cultivation is seen in the case of the sweet Orange, for this has been derived from the bitter variety which was the original stock. When seeds of sweet Oranges are planted, a certain number of the seedlings usually revert to the ancestral stock, and produce trees which bear sour or bitter fruit. This tendency to **reversion** is very common in cultivated varieties, and would lead to their extinction in the absence of artificial selection and propagation.

325. **Life-History of a Plant.** The life of a flowering plant does not in all cases follow precisely the same course, although great uniformity is exhibited for the most part; the seed giving rise to a seedling, which after growing and vegetating for some time flowers and produces new seed. One variation from the typical life-cycle is of very general occurrence, and takes place whenever a new plant is produced from buds or cuttings without the intervention of seeds. This is what is known as vegetative reproduction, and it occurs as a normal phenomenon in bulbs, tubers, and in such plants as produce runners, stolons, suckers, etc. There are, in addition, many minor differences between the different plants, as regards their duration, their time of flowering, and their behaviour during successive vegetative periods. Moreover, all plants do not behave similarly during the changes of season, although in the case of the perennial plants of North Europe a summer period of intense activity alternates with a period of quiescent hibernation in winter.

That a plant should live, grow, and produce flowers, fruits, and seeds continuously and indefinitely is perfectly conceivable, but, as a matter of fact, the *expenditure* during the period of seed-production is usually much greater than the *income* of the vegetative shoot at this time. Hence plants usually store up food for some time before flowering. This implies the introduction of *rhythm* or *periodicity* into the history of the plant, and the description of the stages of the growth, maturity, and decay of a plant constitutes its *Life-history*.

326. **Effect of Changing Seasons.** The special stimuli requisite for normal protoplasmic life have been seen to be *free oxygen*, *water-supply*, and *temperature*. The percentage of oxygen in the atmosphere is fairly constant all over the world, although the percentage in the soil varies considerably. The temperature and water-supply vary enormously with (1) *climate*, (2) *seasonal changes*. The simple *Life-history Cycle* thus becomes *greatly complicated* in correlation with these two factors, and in all parts of the world, except certain regions of the moist Tropics, the influence of the rhythmic alternation of the seasons is deeply felt. This influence of annually changing seasons is generally felt in the form of *one season being unfavourable for growth*. This is due to

(1) Too little water.
(2) Too little heat.
(3) Too much heat and too little water combined.

Plants therefore require to live protected against

(1) A dry season (Drought).
(2) A cold season (Winter).
(3) Hot dry season (Desert condition).

The various modes by means of which plants manage to persist in a more or *less dormant* condition over unfavourable seasons is included under the term *Perennation*.

In this country the facts of perennation are so familiar that they are often overlooked, and they are almost wholly correlated with *winter-cold*.

Very few British plants are dormant in summer—viz. Snowdrops. In hot and especially in desert countries the perennation period corresponds to the hot season, and vegetation continues in the wet season.

327. **Winter Perennation.** In adaptation to their surroundings the plants of cold climates have acquired various means of surviving the cold period of the year. Except in the case of evergreens, which usually retain their leaves for two or three years, the leaves usually die and fall off at the onset of winter, although many of our English herbs, including the commoner grasses, retain their leaves in a more or less damaged condition until the following spring, especially if the winter is a mild one, or if snow lies thickly on the ground. The parts above ground are more exposed to extremes of tempera-

ture than are the roots buried in the soil; nevertheless the stem and branches of shrubs and trees withstand severe cold, largely owing to the protective jacket of cork which covers them. Even when the roots remain living during winter, the root-hairs may diminish in number or disappear, and owing to this fact, and to the difficulty of absorbing water from cold or frozen soil, evergreens often suffer severely during hard frosts, for, although the stomata are closed, the leaves may lose water more rapidly than it can be supplied to them by the roots, and hence they shrivel and die. This is why a dry, cold, east wind is more hurtful to our indigenous plants than a moist but equally cold west wind. Indeed in all cases the danger of a deficiency of water is quite as potent a factor, though an indirect one, in inducing the winter-resting period, as is the low temperature, which acts directly upon the plant, lowering its vital activity. It is the same danger of desiccation during winter which has caused the leaves of our evergreens to become leathery, or to acquire thick cuticles. The layer of cork which covers the stems of shrubs and trees enables them to withstand cold, mainly because it protects them against the loss of water, and to a less extent because it acts as an insulating jacket, and keeps in heat just as a blanket would do.

328. **Drought Perennation.** In tropical climates the seasons are determined not so much by the temperature as by the amount of rainfall. It is only in a few regions, where the wet season continues almost without intermission during the entire year, that the vegetation grows uninterruptedly from season to season, as is the case in some parts of Java, Central Africa, and Brazil. Typically one or two wet and dry seasons occur each year in alternate succession, and if the dry season is at all prolonged, the vegetation suffers a pronounced check. In those tropical regions where no rain falls for months at a time, every green leaf may wither and fall, except in the case of a few xerophilous plants,* which are especially resistant, or in the case of plants that chance to grow near some constant source of water (*desert-oases*). The special adaptations by which plants are enabled to survive periods of drought are very similar to those exhibited by the plants of cold climates, which each season must successfully withstand a shorter or longer exposure to severe cold. Thus in both cases trees and shrubs lose their leaves, while plants with underground perennial, tuberous, bulbous, or rhizomic stems are characteristic of dry, arid regions, and occur equally commonly in cold climates. Under exceptionally severe conditions annual plants have a distinct advantage over all others, since their seeds are, in most cases, not injured by drying, and equally unaffected by frost. Hence annuals may exist where trees and shrubs cannot develop, and where even plants with perennating underground parts can maintain themselves only with difficulty.

* These are plants adapted for growth in dry regions. They have thick cuticles, a reduced leaf-surface, and frequently fleshy or leathery leaves, or fleshy stems and no leaves. See pp. 370-1.

329. **Modes of Perennation.** These may be summarised as follows:

1. *The Evergreen Tree.* The *foliage persists,* but is *protected.*

2. *The Deciduous Tree.* The foliage is shed for *winter-cold* or *summer-drought.* The *shoot* is protected by its cork jacket, and the growing-points perennate as *buds,* covered by protective scales.

3. *Herbaceous Perennials.*
   - (i) Only the flowering shoot dies, as in summer-flowerers such as Buttercups.
   - (ii) *All the aerial portions die,* as in most plants with rhizomic stems.

4. *Special Types of Subterranean Perennation.*
   - (*a*) *The Bulb.*
   - (*b*) *The Corm.*
   - (*c*) *The Rhizome.*

   The Bulb and Corm may be regarded as perennating buds, while the Rhizome is a stem which has gone below ground for protection.

5. *Seed Perennation.* This is the most perfect type of perennation known, for the dried dormant plantlet provided with food-materials and enclosed in its protective coverings retains its vitality often for many years and under most adverse circumstances.

Duration and Seed-Production. Plants may be classified into annuals, biennials, and perennials, according to whether their life-cycle is completed within one, two, or several years. Again, plants are either **monocarpic** and completely exhaust themselves the first time they produce seed, or are **polycarpic** and spread their production of seeds over several seasons. Hence of necessity annuals and biennials are monocarpic, whereas perennials may be either polycarpic or monocarpic.

330. **Perennials.** (*a*) Polycarpic. The herbs, shrubs, and trees comprised in this group continue to bear fruit and seed season after season once flowering has begun. Several years usually elapse before the first flowering of shrubs and trees, and although such herbaceous perennials as the Daisy, Plantain, and Dandelion usually flower during their first season, in others flowering is delayed for one or more years. The duration of polycarpic perennials may be

almost indefinitely prolonged (several hundred years in the case of some trees), death finally occurring as the result of accident, disease, or exhaustion.

(*b*) Monocarpic. Only a few perennials are monocarpic, and they may either be arboreal (many Palms, and the Giant Bamboo) or herbaceous, as in the slowly growing Century Plant (*Agave*). Such plants vegetate, grow, and store up food-materials often for more than twenty or thirty years, at the end of which time they produce a great crop of fruits and seeds and die exhausted.

331. **Biennials** (Monocarpic). These devote their first season to accumulating food, which is stored in the root (Carrot, Parsnip, Beetroot), or in the hypocotyl (Turnip, Radish). After perennating through winter, they utilise their surplus food in producing a large number of flowers and fertile seeds, and then die. If exhaustion is prevented by cutting off the fruits before they grow, life may be prolonged almost indefinitely. Many plants popularly classed as biennials, because they flower in their second year, grow as perennials when undisturbed (Foxglove, Snapdragon).

332. **Annuals** (Monocarpic). These afford the most perfect case of perennation, in which the whole plant dies at the end of the first season, and the species is maintained from year to year by **seeds**, which under normal conditions perennate over winter in the soil. Indeed many seeds may remain dormant in the soil for several years, and germinate when the vegetation which has suppressed their parents is removed.

In some annual plants termed *ephemerals*, the duration of the life-cycle is so shortened as to enable several generations to follow one another during a single season, only a few weeks intervening between the germination and fruiting of each individual (Shepherd's Purse, Chickweed, Groundsel). The Groundsel in fact grows and fruits all the year round.

There is, however, no sharp distinction between annuals and "ephemerals," for the former may go through two or even three generations when the favourable seasonal period is unusually prolonged, and an ephemeral may only have time for a single life-cycle when the seasonal period is very short, as in Alpine and Arctic regions.

Both the duration of a plant and the number of times it may flower are liable to be modified by external circumstances. Many annuals may become biennials if a wet summer or rich soil retards flowering, and if the winter frosts are not so severe as to kill them. Most annuals are killed by frost when adult, but not as seedlings (Poppy). Starved annuals may become ephemerals by shortening their life-cycle. Such plants as the Castor Oil and Scarlet Runner are perennials in warm climates, but become annuals in cold ones, since they are killed by the winter frosts, whereas their seeds survive.

On the other hand the existence of many annuals is prolonged

when they are not allowed to fruit and seed (*e.g.* Mignonette), and the biennial Foxglove may, under favourable circumstances, flower for three or four seasons. Again, Wheat ripens within a short season of three months in north India, whereas in England it is grown as a biennial, being sown in September or October, and not harvested until the following July or August. If planted in Spring flowering would take place so late in the year that the cold would prevent the formation of perfect seeds.

333. **The Geographical Distribution of Plants.** We have already seen that a certain temperature, a supply of oxygen, water, and carbon dioxide, an appropriate substratum and exposure to light, are all essential conditions for the growth of green plants, although in the case of parasites and saprophytes the presence of carbon dioxide may always, and exposure to light usually, be dispensed with. In every case the plant can only grow when these essential conditions are fulfilled, and the intensity, concentration, or amount of each such factor must not fall below, or rise above, certain limits. For example, there is a certain optimal supply of water, carbon dioxide, light, etc., at which growth is most rapid, while below the minimal or above the maximal amounts it rapidly or gradually ceases. In some cases—as, for example, in the case of submerged water-plants—the optimal supply of water is also the maximal, and, in fact, the position of these three cardinal points for each factor differs greatly according to the plant examined. Usually, however, the minimal and maximal points lie fairly wide apart, so that the same plant which grows best under a special set of conditions may be able to prolong a more or less enfeebled existence when these conditions have undergone more or less modification in one direction or the other. Some *cosmopolitan* plants indeed possess such pronounced powers of adaptation that they are able to exist in almost every part of the globe. Certain factors, such as light, moisture, and soil, influence more especially the local distribution of plants, whereas others, such as temperature, and in some cases moisture, also determine the general or geographical distribution of plants over wide areas. The possible range of any given plant is in all cases determined by the character and mode of life of the plant itself, and by its powers of accommodation and

distribution. By slightly changing the former the plant may be able to progress from one zone to another if its seeds are widely dispersed, and the offspring, by adapting themselves to the altered conditions in the new zone, may ultimately come to diverge widely from the parent species. The local distribution of plants is often due to the fact that the seedlings are only able to withstand the stress of competition with other plants when the conditions are specially favourable to them or unfavourable to their competitors.

We are, of course, chiefly concerned here with the local distribution of plants; but, before proceeding to study the vegetation of our own country, it is well to gain some information about the general distribution of plants, which will help us to understand more fully the conditions on which plant-distribution depends.

The distribution of plants on the earth's surface is dependent upon (1) the environment, (2) the powers of dispersal, (3) the existence of barriers to migration, (4) the distribution of plants in the past.

334. **Environment.** This includes not only the non-living, but also the living surroundings. The former includes (*a*) temperature, (*b*) moisture, (*c*) light, (*d*) soil or other medium; the latter includes (*e*) other plants, (*f*) animals, (*g*) man.

335. **The Temperature** influences all plant functions to a pronounced extent. Growth, cell-division, carbon-assimilation, and life-processes in general, all decrease as the temperature falls and cease in most plants at or about 0° C. They take place most actively at from 20° C. to 30° C. in most cases, and usually cease above 40° to 45° C., although a few Bacteria and Algae are accustomed to the much higher temperatures of certain hot springs. Respiration, on the other hand, may continue feebly even below the freezing-point of water, and increases steadily as the temperature rises until the plant or cell is killed.

Transpiration is also accelerated by high temperatures, and diminished by low ones, provided that the stomata remain open, and that the air is correspondingly saturated with water-vapour in both cases. In hot *moist* air, how-

ever, transpiration may be less active than in fairly cold but *dry* air.

On the whole, most plants prefer temperatures lying between 20° and 30° C., although many are specialised to withstand very high or very low temperatures. We may distinguish between (*a*) **heat-lovers**, which only develop in tropical regions; (*b*) **cold-fearers**, which grow more especially in warm temperature and sub-tropical regions, and are killed by frost; (*c*) **cold-bearers**, which are able to survive the frosts of winter in various ways (cf. the modes of perennation already given).

(*a*) The temperature of any region depends upon (1) its latitude, (2) its height above sea-level, and (3) upon its distance from the sea. Four regions can be recognised.

336. In the **Torrid** zone, lying between the Tropics, the average annual temperature lies between 26° C. and 32° C., and the climate being moist, the vegetation undergoes hardly any check by cold or drought. Characteristic tropical plants are Palms, Bamboos, Tree-ferns, Screw-pines, Peppers, Begonias, and climbing or epiphytic Ferns, Orchids, Aroids, etc. Included within the tropics are also certain desert regions where little or no vegetation grows—viz. Central Africa and parts of South America. Tropical plants can only be grown in hot-houses in Britain.

337. In the **Warm Temperate** or sub-tropical zone the average annual temperature lies between 13° C. and 25° C., and does not sink at the cold winter period (January in north hemisphere, July in south hemisphere) below 5° C. Hence the plants of this area can be grown in greenhouses if they are protected from frost. The extremes of temperature are greater than in the Tropics, and a large part is either subject to drought or has periodical rain-falls. The vegetation of such regions is naturally more or less strongly xerophytic. The flora, though less luxuriant than that of the Tropics, contains a large number of species. Very many of the plants are bushes or low shrubby trees. Terrestrial Orchids replace the epiphytic ones characteristic of the Tropics. Annuals, mosses, lichens, and cereal and pasture grasses appear, spreading hence to the northernmost limits of the temperate regions, and in the first three cases even beyond that. The characteristic features of this zone are (1) the abundance of shrubby plants and grasses, the latter mostly intermediate in size between Bamboos, the chief tropical representatives of this order, and our small Northern forms; (2) Rice and Millet are replaced by Maize and Wheat; (3) Cotton appears, and the Palms decrease in number. About three-quarters of the known species of plants (about two hundred thousand) occur in this and the preceding zone, whereas the entire Arctic flora comprises hardly more than one thousand species.

338. In the **Cool Temperate** zone the average annual temperature lies between 40° F. and 60° F., and the period of active vegetation lasts only for six months. The flora is still less abundant than that of the former regions, and its character is largely determined by the necessity of surviving the cold winter period. Nearly all the trees are deciduous, and are bare of leaves for half the year; but a few are evergreens, and exhibit various xerophytic characters to guard against, not so much the cold of winter, as the danger of an insufficiency of water when the roots are unable to absorb from the soil. The herbaceous plants are mostly perennial, and great forests containing only one kind of tree are a common occurrence. The various modes of perennation in herbaceous plants have already been fully discussed.

339. **Arctic and Alpine Regions.** There are about eight hundred species of plants which grow within the Arctic circle, whereas probably two or more thousands of similar plants grow upon the summits of the various ranges of the lofty mountains where the climate approaches Arctic severity. Many of these plants have ascended from the lower regions, and either become adapted to the altered conditions of temperature by developing into new Alpine species, or are possessed of sufficiently flexible constitutions to withstand the greater cold. The Arctic-Alpine flora is characterised by the small size of the plants, by the dwarfing of the shrubs and bushes, and by the relative abundance of mosses and lichens. Many of the plants have the leaves in close rosettes, narrow, hairy or fleshy. Several species of *Salix*, *Rubus*, and *Andromeda* occur in the Arctic regions, and the following genera are represented by Alpine species: ***Ranunculus*, *Primula*, *Juncus*, *Carex*, *Gentiana*, *Saxifraga*, *Potentilla*, *Arabis*, *Silene*.** The Arctic zone is that around the poles, and its flora is very limited, whereas the Alpine zone includes the tops of the higher mountains in all the other zones, and has a more diverse flora. Very often a plant occurring in the Arctic region is represented in several Alpine districts by different species belonging to the same genus, although the latter may not occur in the intervening tracts of land. This can come about in one of two ways: (1) the temperature may have been lower in past ages (glacial period) than it is now, and as the temperature rose the Arctic plants could only find suitable conditions for existence on the tops of lofty mountains or in the Arctic regions, dying out in the intervening valley and plains; (2) genera which have enjoyed a temporary success and acquired a wide distribution may be defeated in open competition, and take refuge on lofty mountains where their competitors cannot follow them. In both cases originally similar species occupying widely separated localities will tend to diverge in progress of time, so that a particular genus may be represented by a different species on each of a number of mountain ranges. Certain species, showing xerophilous characters, are common to sea-coasts and mountains (see p. 366).

340. **Moisture.** Within the Tropics dry and wet seasons alternate in regular succession, farther north and south comes an almost rainless zone, and in the temperate regions we have variable winds and rain. These three regions are characterised by plants which differ as regards the amount of moisture they require. Thus in the Tropics a great abundance of *hygrophilous* (moisture-loving) plants is found which can only exist under moist conditions, while in the dry regions mainly *xerophilous* plants are found, which require but little water, and can survive prolonged periods of drought. The plants of temperate regions lie mostly between these two extremes. Hygrophilous plants are usually of large size and luxuriant, devoid of prickles or thorns, and with an abundance of stomata and a thin cuticle. Most Ferns and Palms, Bananas, etc., are hygrophilous. Xerophilous plants have either succulent or very hard shoots, either no leaves, or fleshy or leathery ones, or phyllodes as in *Acacia*. Hairs, scales, glands, prickles, and thorns are commonly present. The cuticle is thick and often covered with wax. Tuberous roots or shoots are common, and the main stem is often underground. Cactuses are typical xerophytes, and so also are very many Acacias and Euphorbias.

341. **Light** determines mainly very local distribution, some plants loving the shade (Wood-sorrel, Cow-wheat, Sweet Violet, and Wood Geranium) and others full exposure to the sun (Field Poppies, Sunflowers, Sun Spurge).

342. **The Substratum,** taking this term in the widest possible sense, also determines very local distribution. Many plants grow only in bogs and swamps (Rushes, Bog Mosses, Sundews, etc.), others in peaty soils or in soils rich in vegetable remains (Rhododendron, Erica, Bird's-nest Orchid), others again in or on running or stagnant water (Reeds, Duckweed, Elodea), others on sandy or muddy coasts (Salt-wort, Seakale, Sea-lavender, Sea-holly). Similarly some plants prefer chalky soils, others rich loam, while some succeed in maintaining themselves on the poor thin soil derived from granite rocks. It must, however, be

remembered that plants grow largely where animals or other plants will let them, and hence a plant may inhabit a poor soil not from choice, but from necessity.

The influence of man is mainly displayed in cultivated plants, some of which have been traced back to the Stone Age. For example, the cultivated Flax (*Linum usitatissimum*) has been derived from the perennial Flax (*Linum perenne*), but under the influence of cultivation has diverged so widely from the ancestral form as to become a distinct species, which is now much more abundant than its prototype. The latter plant is very variable even at the present day, and it might indeed be possible to derive other species from it.

343. **The dispersal** of seeds and fruits by wind, water, and animals, as well as by movements of the plants themselves, has already been discussed (Ch. VII.).

The chief barriers to migration are deserts, saline tracts, seas, rivers, lakes, and mountains.

The influence of the **past distribution** of plants is often very great, and this, together with the existence of barriers to migration, is responsible for the fact that similar but widely separated regions may contain very dissimilar floras. Plants never occupy all the areas suitable to them. For example, several British weeds introduced into Australia and North America have found there a suitable soil and climate, and hence have spread rapidly, although they might never have reached these continents but for the agency of man.

344. **Water-Plants** are subject to less extremes of temperature than land-plants, for the water in which they grow takes longer to be heated and longer to cool. The percentage of carbon dioxide in water is higher than in air, since this gas dissolves readily in water. The submerged leaves of a water-plant are usually either long and strap-like, as in *Glyceria fluitans*, a water-grass; or narrow and arranged in whorls, as in Water Starwort (*Callitriche*); or divided into numerous fine threads, as in Water Butter-cups. These submerged leaves have chlorophyll in the

epidermis, which bears no cuticle, so that water containing dissolved salts and gases can pass in freely. Since the submerged parts get their salts, oxygen, and carbon dioxide directly from the water, there are no stomates, nor does the stem contain many wood-vessels, and the roots serve chiefly to fix the plant to the bottom, having few or no root-hairs, since root-absorption is not required. As we have seen, a land-plant requires to have its stem and leaves strengthened by hard tissue, arranged so as to resist the strains caused by weight and by wind. In a water-plant the weight is, of course, supported by the water, and the only strain to which fixed submerged plants are subject is a pulling-strain due to movement of the water, especially in fast streams. For these reasons there is little or no special mechanical tissue outside of the vascular bundles, and the latter are placed in the centre of the submerged stem, as in the *root* of a land-plant. Leaves which float on the surface of the water are entire and rounded or slightly lobed (Water-lilies, Pond-weeds, Duckweed, some Water Buttercups), and bear stomates on their upper surface, which is covered with cuticle or wax so as to prevent wetting. These floating leaves have the same structure as those of land-plants, but the air-spaces are very large and are continuous, with air-passages running down the leaf-stalk to the submerged stem and roots. Air-spaces are present in submerged plants too, as well as in the stems of plants which grow with only their lower parts in the water—*e.g.* Mare's-tail, Rushes, Sedges. In submerged plants these air-spaces enable the plant to float upright, but they also convey air to the lower parts growing in deep water or in mud, where little or no oxygen is present for respiration.

Since a submerged plant gets water, salts, carbon dioxide, and oxygen so easily, and lives in very favourable conditions generally, it grows rapidly, branches freely, and reproduces itself largely by vegetative means, chiefly by the decay of the older parts setting the branches free, or by branches breaking off. The water-plants of tropical regions grow continuously all the year round, not being hampered by either a cold or a dry season. In temperate regions growth is interrupted by the winter, and various methods

of perennation occur (practically all water-plants are perennial). In some cases—*e.g.* *Callitriche*—the plant remains unaltered, merely sinking to the bottom; in Water-lilies, food is stored up in the rhizome; in Arrow-head, tubers are formed. A very common mode of perennation is the formation of winter-buds, which are developed at the ends of the branches. These buds are large, their leaves contain reserve food; they drop off and remain at the bottom during the winter, growing up in the spring. Winter-buds of this kind occur in Water Milfoil, Water Violet, Bladderwort, Frog-bit, and various species of *Potamogeton* (Pond-weed). Since water-plants reproduce themselves so extensively by vegetative methods, it is not surprising that they usually flower much less freely than land-plants. In a few cases the flowers are adapted for pollination at the surface or even under water. In most water-plants, however, the flowers are formed above the water, and are adapted for pollination by wind or by insects. In the former case much of the pollen must fall into the water and be wasted; in the latter, the scarcity of insects makes the chance of cross-pollination small.

Fig. 185. — Ranunculus Aquatilis with Lobed Floating Leaves and much-divided Submerged Ones.

The plants mentioned so far grow with the entire shoot under water (except the flowering branches) and the leaves submerged or floating. In some Water Buttercups part of the shoot remains below and bears divided leaves, while part grows upwards and bears broad, floating, or aerial leaves (fig. 185). Some plants—*e.g.* *Polygonum amphibium*, *Littorella* (Shore-weed, on margins of mountain-lakes)—can grow either submerged or on muddy soil with their shoots in the air. In such amphibious plants the leaves of the land form are broader, and the stem- and leaf-structure resembles that found in ordinary land-plants. In the case of many

water-plants it is found that they can be grown on land, either by transplanting them to ordinary soil or by sowing the seeds in soil: in the former case the new shoots formed differ from the water-form in regard to leaf-shape and the leaf- and stem-structure; in the latter case the seedlings produce at first some leaves of the aquatic type, and later bear broad land-leaves. These experiments should be tried, as well as the reverse kind of experiment—*i.e.* transplanting, or germinating seeds of, land-plants in mud, very wet soil, or in water. In some cases the change from land-plant to water-plant can be brought about, especially with plants which grow ordinarily in damp places.

Some plants grow in shallow water, but send up their leafy and flowering shoots into the air. These will be included under the heading of "Marsh-plants."

345. **Marsh-Plants.** Between submerged water-plants, moisture-loving plants, and ordinary land-plants there is every stage of transition. We can, however, distinguish between truly aquatic plants and those characteristic of marshes and bogs. The former are permanently submerged in water, whereas bogs and marshes occur where the substratum alternates between long periods of submergence and shorter periods of more or less complete drying-up. As we have seen, submerged water-plants get oxygen and carbon dioxide, in addition to salts, from the water, hence they occur mainly in water which is moving, or at least often removed. On the other hand, water-plants with floating or with aerial leaves can grow in stagnant pools or ditches where there is little oxygen, and where organic acids and marsh gas are abundant. The same is true of marsh and bog plants, whose characteristic feature is that their lower parts, buried in the stagnant mud, are adapted to life in water, while their upper parts, exposed to the air, either resemble those of ordinary land-plants or have leaves adapted to withstand periods of drought. The reduced leaf-surface and thick cuticle of Rushes, Sedges, etc., which are characteristic of xerophilous (drought-resisting) plants, are probably due to the fact that stagnant mud (especially in peat-bogs) contains acids

produced by the decaying organic matter (humus), whose presence makes it difficult for the plants to absorb water.

The plants found on the muddy margins of ponds and streams, as well as in marshes and swampy ground, include various Horsetails (*Equisetum limosum*, *E. palustre*), tall Sedges, Rushes (*Juncus*), Grasses; Bulrushes (*Typha*), Bur-reeds (*Sparganium*), Water Plantain (*Alisma*), Arrowhead (*Sagittaria*); Marsh Arrowgrass, Yellow and Purple Irises, Marsh Orchis, Willows, Alder, Water Docks (*Rumex conglomeratus*, *R. hydrolapathum*), Water-pepper (*Polygonum hydropiper*), Ragged Robin, Bog Stitchwort, Marsh Marigold, Lesser Celandine, Spearworts (*Ranunculus lingua* and *R. flammula*), Water-cress, Cuckoo-flower, or Lady's-smock (*Cardamine*), Meadow-sweet, Water Avens, Golden Saxifrage, Purple Loosestrife (*Lythrum*), Willow-herbs (*Epilobium palustre*, *E. parviflorum*, *E. tetragonum*), Mare's-tail (*Hippuris*), square-stemmed St. John's Wort, Water Dropworts (*Oenanthe*), Water Parsnips (*Sium*), Marshworts (*Helosciadium*), Common Hemlock (*Conium maculatum*), Marsh Pennywort (*Hydrocotyle*), Yellow Loosestrife (*Lysimachia vulgaris*), Moneywort or Creeping Jenny (*L. nummularia*), Water Forget-me-Not, Marsh Woundwort, Water Mint, Pennyroyal, Gipsy-wort, Water Speedwell (*Veronica anagallis*), Brooklime (*V. beccabunga*), Marsh Speedwell (*V. scutellata*), Red Rattle (*Pedicularis palustris*), Marsh Figwort (*Scrophularia aquatica*), Marsh Hawk's-beard (*Crepis paludosa*), Water Ragwort (*Senecio aquaticus*), Hemp Agrimony (*Eupatorium*), Bur Marigold (*Bidens cernua*), Marsh Cudweed (*Gnaphalium uliginosum*), etc.

346. **Bog-Plants.** The typical bog occurs on heaths and moors, associated with Heathers and other heath-plants, and its vegetation consists of peat-forming and peat-loving plants. The distinctions between a marsh and a bog are fairly clear in most cases, though there are transitions from one to the other. The typical marsh occurs on low ground, its water is rich in mineral substances, especially lime, and its plants grow rapidly, either becoming tall or remaining low, but producing numerous leaves and branches each year. In the typical bog, the water is poor in lime

and other salts, and the plants are mostly slow-growing and of low stature. Peat-bogs, like the heaths or moors on which they occur, are found at all heights, from a few feet above sea-level up to three thousand feet. The peaty soil in which bog-plants grow is not sufficiently aerated for the proper formation of nitrates, so that although such soils (bog, peat, morass) often appear on analysis as though they should be extremely fertile, very little of the materials they contain is directly available to serve as plant-food. As already stated, some heath and moorland plants (Heathers, etc.) are able to make use of peaty materials by being partial saprophytes (Ch. VIII.), but this power is not possessed by the majority of bog-plants (Rushes, Sedges, Bog-mosses, etc.). As in the case of many marsh-plants, most bog-plants have more or less well-developed xerophilous characters, due largely to the excess of peaty acids, which makes water-absorption difficult. Mosses, especially the Bog-mosses (*Sphagnum*), of which many species and varieties have been distinguished, play an important part in the formation of bogs. The Bog-mosses, whose appearance and remarkably spongy character are well known to all who have walked over our moors, are specially adapted for storing water. The leaf of a Bog-moss consists of a single layer of cells, which are of two kinds: (1) large empty cells with pores on the walls, (2) small green cells. The green cells are long and narrow, forming a network, each mesh of which is occupied by one of the empty cells; the green cells carry on the living functions, while the large clear cells store up water. Each plant branches and grows upwards, while the lower parts die and lose their green colour, but are preserved from decay by the absence of oxygen and the presence of the peaty acids. In this way great masses of peat are formed.

The flowering plants found in bogs include Ericaceae (Ling, Heather, Bilberry); Sedges, Rushes, and Grasses, mostly different from the kinds found in marshes or wet meadows; Bog Asphodel, Bog Orchids, Bog Myrtle, Grass of Parnassus, Bog Cinquefoil (*Comarum palustre*), Sundews (*Drosera*), Marsh Gentian (*Gentiana pneumonanthe*),

Bog-bean (*Menyanthes*), Bog Pimpernel, Butterwort, Bladderwort.

As already stated, peat is very poor in available plant-food, and this fact largely accounts for (1) the xerophilous character of most bog-plants, (2) the presence of mycorhiza in the roots of Heathers and of heath-grasses (Ch. VIII.), (3) the presence of insectivorous plants like Sundew and Butterwort in bogs.

347. **Moorland Plants** are exposed to high winds, which not only increase transpiration, but prevent the growth of trees. This is not so marked on low moors (heaths), where such trees as Pines and Birches flourish, but on high moors the entire vegetation is dwarfed and stunted. On the highest parts of a moor, like those of Yorkshire and Devonshire (Dartmoor), the rainfall is high and frequent. On the summit of Dartmoor (including the area around Cranmere and Fur Tor, where all the great rivers of Devon arise from an intricate network of boggy crevasses which gradually give rise to streams), the aspect of the vegetation is dreary in the extreme, both in summer and winter, though livened in early summer by the white fruits of the Cotton Grass, which form snow-like patches. The chief plants found on this boggy plateau are Cotton Grass and Ling (*Calluna*), mixed with tufted Grasses having narrow rolled-up leaves, together with cushions of dry Mosses, while the wetter parts consist almost entirely of Bog-mosses. Farther down, as well as on the wind-swept outlying ridges of the moor, the dominant plant is usually the Bilberry (*Vaccinium myrtillus*) in the drier parts, with Sedges, Rushes, and Bog-mosses in the swamps and along the water-courses. On low-lying heaths we find chiefly Ling and Heathers (*Erica cinerea*, *E. tetralix*), Gorse, Bracken, with low creeping plants which shelter under these—*e.g.* Tormentil, Heath Bedstraw—and in the wetter parts the various bog and marsh plants already mentioned.

The leaves of Ling, Heaths (*Erica*), and Crowberry* are

* *Empetrum nigrum*, a heather-like plant in general appearance, though not belonging to Ericaceae. It is rare in the south of England, but is abundant on some moors in the north.

rolled up so that the lower epidermis (bearing the stomates) forms the inside of a tube which is open to the air by a narrow slit (seen as a white line along the lower side of the narrow leaf); the edges of the leaf bear hairs, which still further hinder the escape of water-vapour from the leaf. Bilberry has broad, thin leaves, but these fall off early, and the ridged green branches carry on photosynthesis without exposing much surface for transpiration. Sedges and Rushes have narrow leaves with thick cuticle, while heath-grasses bear on their upper surface triangular ridges, and can roll up longitudinally in dry weather so as to expose a very small surface for transpiration (the green tissue, with stomates, lines the furrows between the ridges). The leaves of Bracken-plants growing on heaths have thicker cuticle, less spongy tissue, and fewer stomates than those of Bracken growing in moister and more sheltered places; the same applies to other species which grow both on heaths and in less exposed places.

348. **Humus Plants.** Some of these simply prefer the humus as a medium on which to grow. This applies to the Crowberry (*Empetrum nigrum*), the Cranberry (*Vaccinium*), and the Rhododendron. Others, however, are saprophytes, and use the humus as a source of food. They are aided in this by the presence of symbiotic fungi (mycorhiza) on their roots, which play the part of root-hairs, and after decomposing the humus, hand over all or a portion of it in a suitable form to the plant. Plants of this kind commonly have their foliage leaves reduced to mere scales, as in the Bird's-nest Orchid. When (as in Heather) the leaves are fully developed, the mycorhiza probably enables the plant to absorb nitrogen from the humus, and not carbon.

Humus collects in most bogs and swamps, but here it is the water which is of primary importance in influencing distribution.

349. **Chalk-Plants.** Of plants which prefer or are in some districts entirely restricted to calcareous soils, may be mentioned the wild Columbine, the Lily of the Valley, the Fly and Bee Orchis, the common Rock Rose, the Bloody

Crane's-bill (*Geranium sanguineum*), Stinking Hellebore (*Helleborus fetidus*), Traveller's Joy (*Clematis*), Yellow Gentian (*Chlora*), *Campanula glomerata*, Whitlow-grass (*Draba muralis*), Dyer's Weed (*Reseda lutea*), Wild Flax (*Linum perenne*), Dogwood (*Cornus*), Wayfaring Tree (*Viburnum lantana*), Mouse-ear Hawkweed (*Hieracium pilosella*), Privet (*Ligustrum*), Verbena, Deadly Nightshade (*Atropa*), Hound's Tongue (*Cynoglossum*), Pasque Flower (*Anemone pulsatilla*).

Chalk soils are usually dry, and, in dry continental climates, plants which grow in almost all soils in England may be unable to develop on the calcareous regions of the continent. Thus the white Birch, *Hypericum pulchrum*, *Stellaria holostea*, *Galium saxatile*, and Broom are all absent from the calcareous Jura mountains, but grow freely upon the Vosges, on which the soil is formed of decomposed granite, and also in marl soils in which the presence of some clay renders the soil more retentive of moisture.

350. **Pure Clay** does not form a soil preferred by any flowering plant, and is highly unsuitable to most. When dry the soil bakes hard, and is almost impenetrable by the roots, while the very fact that when moist it is highly retentive of water, renders it difficult for the plant to absorb sufficient water unless the soil contains a large amount. In this case the soil is very badly aerated, and hence for lack of oxygen the roots are unable to develop to any great extent or to penetrate deeply. If mixed with sand, chalk, or humus, however, the soil is much improved, and many plants will survive periods of drought on such soils, whereas they may perish on more porous ones. Such plants as Lily of the Valley (*Convallaria*), Lesser Celandine, Wood Sanicle, Coltsfoot, Primrose and Cowslip, Bittersweet (*Solanum dulcamara*), Yellow Dead-nettle (*Galeobdolon*), Garlic, Early Purple Orchid (*Orchis mascula*), Blue-bell (*Scilla nutans*), are found, in some districts at least, to prefer soils containing a good deal of clay.

At this point you should carefully revise the parts of Ch. III. dealing with soils (pp. 103–111).

351. **Sand-Plants.** These include (*a*) those plants which prefer merely a sandy soil, and (*b*) those of the sea-coast (**strand-plants**) which have adapted themselves to the presence of salt. Many such plants grow equally well in ordinary soil, but lose certain of their characteristics, and probably would not survive if left open to free competition. Practically all such plants have strongly xerophilous characters; for example, reduced leaf-surface, thick fleshy or prickly leaves and stems, stunted habit, thick cuticle, deeply sunk stomata, etc. Sand-plants, pure and simple, are often very prickly, thorny, or hairy, whereas hairs are usually absent or few in number on strand-plants.

As instances of sand-plants, the following may be mentioned: Mousetail (*Myosurus*), Sand Spurrey (*Spergularia*), Stork's Bill (*Erodium*), Broom, Wormwood (*Artemisia*), Golden Rod (*Solidago*), Wood Sage (*Teucrium*).

352. **Strand-Plants.** The plants which grow along our shores, either on sand or in mud-flats (salt-marshes), are sometimes called *Halophytes*, or saline-plants. They either prefer salty soil, or grow here because their competitors are more sensitive to salt and are unable to follow them. All strand-plants are more or less xerophilous in character, and this is also the case with regard to plants growing on salt-marshes or muddy shores. Here the plant strives to reduce its need of absorbing water to a minimum, so that it shall not absorb too much salt. Hence the plants are fleshy or leathery, the cuticle is thick, the stomata often sunken, and the leaf-surface often reduced or spiny. Since high winds often prevail, the flowers are usually small, and the seeds are rarely winged, but there are exceptions to both these rules; the Sea-poppy has large yellow flowers, and the Sea-thrift has a persistent membranous calyx, which forms a funnel-like wing on the fruit.

Coast-vegetation varies according to the nature of the soil; rocky shores, sand-banks, or "dunes," and muddy salt-marshes have each their own typical plants, though there are often transitions from one to the other. On rocks and cliffs we find Sea-plantains (*Plantago maritima* with entire fleshy leaves, *P. coronopus* with lobed hairy

leaves), Scurvy-grass (*Cochlearia*), Samphire (*Crithmum*, an Umbellifer, with many-lobed fleshy leaves), Sea-thrift (*Armeria*, with heads of pink flowers), Sea Campion (*Silene maritima*). Several of these plants (Thrift, Sea Campion, Scurvy-grass, and *Plantago maritima*) occur also on high hills inland, but not in the low-lying parts between the hills and the coast.

On sandy shores, close to the sea, we find such plants as Sea-poppy (*Glaucium luteum*, with large yellow flowers and very long fruits), Orache (*Atriplex*, several species, shrubs with mealy leaves and spikes of small green flowers), Sea-beet (with fleshy swollen tap-root), Sea-blite (*Suaeda*, with cylindrical fleshy leaves), Saltwort (*Salsola*, rather like Sea-blite, but with a spine at the tip of each leaf), Sea-convolvulus, Sea-holly (*Eryngium*, an Umbellifer with leaves like those of Holly, and small blue flowers in heads like those of Teazle), Sea-purslane (*Arenaria pelpoides*, with crowded decussate ovate fleshy leaves), Seakale (*Crambe*, with thick fleshy rhizome; leaves 6 in. to 10 in. long, stalked, broad, fleshy; flowers white, in corymbs); Sea-rocket (*Cakile*, like *Crambe*, but annual, leaves only 2 in. to 3 in. long), Sea-spurge (*Euphorbia paralias*, with woody rhizome, fleshy leaves, milky juice as in other Spurges), Sea-milk-wort (*Glaux*, belonging to Primulaceae; a small fleshy plant with creeping rhizome, narrow leaves in pairs; flowers small, axillary, with white or pink calyx, no corolla, capsule opening by five valves). All these plants have either fleshy or leathery leaves, and are either annuals, or, if perennial, have long tap-roots or rhizomes by whose upward growth the plants keep above the surface and avoid being buried by the shifting sand. Further back from the sea we come to sand-dunes in which grow various grasses and sedges. The most conspicuous grass is the Marram-grass (*Ammophila*), whose long rhizomes creep in the sand and send up tufts of long rigid leaves, the long roots being chiefly developed where the leaf-tufts come up; its leaves roll up when the air is dry. Along with these grasses, and farther inland, come the Sand Sedge (*Carex arenaria*, like the Sedge shown in fig. 71, except that its rhizome burrows deeply in the sand, running in straight lines and

sending up shoots bearing tufted leaves, which are therefore arranged in lines along the surface of the sand) and other plants, whose creeping stems and tufted roots bind the shifting sand and thus prepare firmer soil for other plants. Farther from the sea come such plants as Rest-harrow (Ononis), Bird's-foot Trefoil (*Lotus*), Bird's-foot (*Ornithopus*), Thyme, Stork's-bill, Stonecrop, Ling, Heather, etc.

353. **Salt-Marshes** or mud-flats occur chiefly near the mouth of a stream, usually not far from sand-dunes, and are most extensive in the tidal estuary of a river. The vegetation of a salt-marsh is quite distinct from that of sand-dunes, though a few plants occur in both sand and mud—*e.g.* Sea-milkwort, Sea-plantains, Thrift, Scurvy-grass, *Suaeda*, *Salsola*. One of the most typical plants of salt-marshes is the Marsh Samphire or Glasswort (*Salicornia*), which has green or reddish cylindrical and fleshy branches, divided into joints, the leaves being represented only by small teeth at the joints, where also the very small flowers are produced. In the wettest parts of the salt-marsh, which are submerged at high tide, we find, along with Salicornia, a Monocotyledon called *Zostera*, with long narrow floating leaves. Farther inland, out of reach of most tides, occur such plants as Sea-lavender (*Statice*, with woody creepy rhizome, "radical" lanceolate leaves, purple flowers in dense corymbose inflorescence), Thrift, Sea-milkwort, Sea-plantain, Sea Arrow-grass (*Triglochin maritimum*, with long narrow fleshy leaves, long flowering shoot, leafless, and ending in a raceme of yellow-green flowers), Salt Spurrey (*Spergularia*, belonging to Caryophyllaceae; narrow fleshy leaves with scaly stipules, flowers pink), Sea-daisy (*Aster Tripolium*, like the Michaelmas Daisy of gardens, but with fleshy leaves), Golden Samphire (*Inula crithmoides*, a composite, with a stout and rarely branched stem, 6 in. to 18 in. long, covered with narrow entire or slightly lobed fleshy leaves; flower-heads yellow, in a small corymb).

Look for all these plants in their homes or "habitats," and note any others that occur along with them. Notice especially the conditions under which plants live in streams, ponds, marshes, bogs, heaths, chalk downs or limestone

hills, sandy soils inland, and on rocky, sandy, and muddy shores, and the various ways in which the plants you find in such localities are adapted to their surroundings. Sketch the plants, find out the orders they belong to and their specific names, and make sections of the vegetative parts (stems and leaves especially) to see how they differ in structure according to the conditions and surroundings in which they grow. Try experiments which may help you to understand better how plants become adapted to special conditions of life. For example, dig up plants found on the coast, and compare the effect of watering these plants and ordinary herbaceous garden-plants with a solution of common salt or of Tidman's Sea Salt (about a handful to two quarts of water).

Even if you cannot visit the coast or the moors, there is ample scope for study in woods and plantations, hedges and ditches, streams, ponds, and marshes.

354. **Woods and Plantations.** In your study of woods and plantations, notice, in addition to the trees, the undergrowth of Shrubs, Brambles, Bracken-fern, and of smaller plants, and, in regard to the latter, find out the order in which the different plants spring up and flower. The same ground, in a wood not too densely shaded by the trees, bears at different times of the year such plants as Wood Anemone, Blue-bell (Wild Hyacinth), Dog's Mercury, Wood Spurge, Primroses, etc. Many of these woodland plants only grow in shaded places—*e.g.* Wood-sorrel, Cow-wheat, Bird's-nest Orchid, Yellow Dead-nettle. Compare the undergrowth of a Beech or Oak wood with that of a Pine or Larch wood.

355. **Hedges.** Many shade-plants grow in hedgerows, the flora of which presents several interesting features. At the top of a hedge-bank the light is very feeble and the soil dry. Now all plants which grow in dry soils require plenty of light, so that the only plants which can develop at the top of the hedge-bank are either plants with long erect stems, such as the Hedge-mustard, Nettle or Thistle, or climbing plants such as Convolvulus, Hop, Clematis, Goose-

grass. Lower down the hedge-bank, where there is more moisture and light, a great variety of plants may develop, while in the shady ditch beneath we may find at the sides Cuckoo-pint (*Arum maculatum*), Ladies'-smock (*Cardamine pratensis*), etc., and in the water of the ditch, the Water-buttercup, Water-cress, Duckweed, and other aquatic or amphibious plants.

Certain plants such as Poppies and Sun Spurges cannot survive under a shady hedge. Others such as the Garlic, Adoxa, Violet, grow well by fairly damp hedgerows. Others again, such as *Erodium*, *Geranium*, etc., will grow well on the sides of dry hedgerows provided they are freely exposed to light.

The hedge itself most commonly consists of Hawthorn, but often of Gorse, Bramble, Sloe, or of small trees like Willow or Hazel. These have usually been planted, as have, of course, the hedges consisting of shrubs like Laurels, Privet, Rhododendron, etc., around parks and plantations Why do hedges need to be pruned or "cut back," and what is the effect of this operation? Notice that plants like Dead-nettles, Yellow Toadflax, Campions, Stitchwort, when growing close to the hawthorn (or other shrub forming the hedge) push up between the branches and have long weak stems, although the same species, when growing some distance from the hedge, has short erect stems with closely arranged leaves. Cases like these suggest the way in which plants, originally erect and self-supporting, may have become climbers through lack of light and the presence of a suitable support.

It is very interesting to compare the nature and general appearance or "habit" of the plants growing along the north and south sides of a hedge which runs east and west. The south side is, of course, warmer, drier, and receives more light, and various plants grow on this side that either do not grow at all on the north side, or are found there in smaller numbers, and showing less luxuriant growth. In the same way the trunk of a tree which is growing in an open situation (*i.e.* not among others in a damp wood) generally has its moister northern side covered with a green powdery Alga (*Pleurococcus*, which is so

common on trunks and palings) and with various Mosses, Liverworts, and Lichens, while the drier south side is usually quite bare. In a damp wood the trunks and branches of the trees are often thickly covered with these "epiphytic" plants, often also bearing Ferns (especially Polypody).

In highly cultivated countries the hedgerows form one of the most important refuges of the original wild plants which covered the country before the advent of the plough. The other chief refuges are by the sides of streams, in stony waste places, and in permanent pastures. In many cases a plant may be able to accommodate itself to very varied surroundings, and such plants have naturally more chance of surviving. Ephemerals, and rapidly seeding annuals, such as the Chickweed, Groundsel, and Field Veronica, may long survive even on well-cultivated arable land, since their seeds may ripen and fall in the intervals between successive weedings.

356. **Terms used in Plant Ecology.** We have seen that various plants grow together in certain localities, evidently because they like (that is, are adapted to) the same kind of soil, the same conditions of dryness or wetness, the same amount of light or of shade, etc. Such groups of plants, growing together in a sort of community, may be called Plant Associations. There are four main ecological types or groups of plants. At one extreme we have plants adapted to life in ponds, rivers, ditches, which grow partly or entirely submerged in water. These true water-plants are said to be *hydrophilous* (*i.e.* "water-loving"), and are termed **Hydrophytes.** Plants which grow in marshes or swampy ground, on river-banks, or on ditch-sides, are said to be *hygrophilous* ("moisture-loving") plants, or **Hygrophytes.** At the other extreme we have plants which are adapted for life under conditions of "physiological" drought—that is, under such conditions that it is necessary to check or greatly reduce the rate of transpiration, or to store up water, or to do both, because the water-supply is scanty or runs through the soil too quickly for the roots to absorb much of it, or because the water cannot be absorbed freely on account of

the presence of excessive amounts of dissolved salts or of peaty matter, or because the plant grows in places exposed to high drying winds, or in cold soil, or exposed to excessive light. A little reflection will show that any of these causes will lead to the development of adaptations for reducing transpiration or of storing the scanty or precarious supply of water which the plant can absorb. In other words, such plants will be *xerophilous* ("drought-loving") plants, or **Xerophytes.** Xerophytes occur on heaths and moors, also in the boggy places which accompany them; on high mountains with an Alpine flora; in sandy localities; on chalk downs; on the sea coast (cliffs, rocks, sandy beaches, sand-dunes, salt-marshes); and in woods or plantations of Pines, Firs, Larches, and other Conifers. Between xerophytes and hygrophytes we find a great many intermediate forms (**Mesophytes**), comprising, in fact, the majority of British plants, which grow in meadows, pastures, cultivated fields, and in woods and plantations of deciduous trees (Beech, Oak, Birch, etc.). These plants show no decided xerophilous or hygrophilous characters, though some approach xerophytes in form and structure and others approach hygrophytes. Woody perennials (trees and shrubs) with deciduous leaves show distinctly xerophilous characters in winter (the protected winter-buds, cork-covering of stems and of leaf-scars, cork-layer closing up the lenticles), while in summer they bear thin leaves like those of mesophytes or hygrophytes. It has been proposed to call such plants, which are more or less hygrophilous in summer and xerophilous in winter, **Tropophytes** (*i.e.* "changing plants"). This applies only to deciduous plants; evergreen land-plants are more or less strongly xerophilous in character, their leaves being usually tough, thick, and leathery (*e.g.* Holly), or needle-like (*e.g.* Pine, fig. 186), and possess thick cuticle, sunken stomates, and other xerophilous features.

It must be remembered that no hard-and-fast lines can be drawn between these types. For instance, some aquatic plants can, when the stream or pond dries up, continue to live and grow, sometimes even more vigorously, in the air, thus changing from hydrophytes to mesophytes. The same

species of plant may be found growing under hygrophilous or xerophilous conditions in different localities. In each case the structure of stem and leaf, as well as the form of the leaves and the general habit of the plant, become

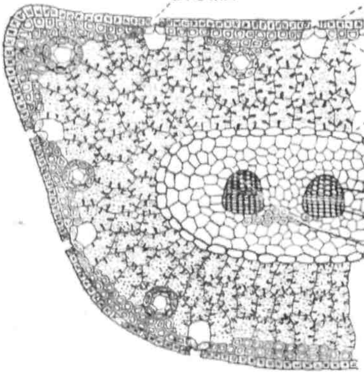

Fig. 186.—Transverse Section of Leaf of Pine.

modified to suit these different modes of life. Coast-plants like Samphire (*Crithmum*) or Sea-plantain can be grown in ordinary soil, and develop thin instead of fleshy leaves.

357. **Field Observations.** It cannot be too strongly insisted upon, that outdoor observations are absolutely essential in studying the distribution of plants and their adaptations to environment. To study this branch of Botany, *i.e.* Plant Ecology, with success, it is necessary to have a good general knowledge of British wild flowering-plants, which can only be acquired by collecting and identifying, as far as possible, all the plants met with (see Art. 321). At first, attention may be confined to the commoner plants and to those which show well-marked adaptations to their environment, and which occur chiefly in sharply defined "plant associations," *e.g.* water-plants, heath-plants, coast-plants.

The student cannot do better than begin field observa-

tions on some definite and fairly uniform area (*e.g.* a sea-shore; pond, marsh, river-bank; heath, common, moor; meadow, cultivated field or garden with its weeds, hedgerow, wood or plantation with its trees and undergrowth, etc.). Study this area at all times of the year, identify as many of the plants as possible, and keep a careful record, with sketches, of your observations. The following hints will suggest the main lines on which the inquiry should be conducted; others will occur as your field-work progresses.

1. Physical and climatic features of the area under observation (*e.g.* chemical and physical nature of the soil; whether retentive and ill drained or porous and well drained; height above sea-level; exposure to, or shelter from, light and wind, etc.).

2. List of the most abundant plants in the area, with notes (and sketches) on the following points in each case: General habit and mode of life (whether annual, perennial, erect, creeping, climbing, xerophytic, aquatic, saprophytic, parasitic, etc.), size, form, texture, etc., of leaves; structure of flowers, with special reference to mode of pollination; structure of fruits, with special reference to mode of seed-dispersal, quantity of seed produced, etc.

3. Reasons why certain species are present in the area under consideration and absent from neighbouring areas, and *vice versâ*. To determine these, compare the physical features of the different areas, and try to map out the whole district into regions characterised by definite plant associations, which will, of course, be found to merge into one another at their edges.

It need hardly be added that the subject of Plant Distribution cannot be mastered by merely committing to memory lists of plant-names. It must be approached in the spirit of observation and inquiry, and the problems it presents answered with reference to the student's knowledge of the Structure and Physiology of Plants.

358. **Trees.** The remainder of this chapter will be devoted to notes which it is hoped will enable students to identify the commoner trees found in woods and plantations. In each case, note the depth of shade which the tree casts

when in full foliage, and the effect this has on the nature and habit of the plants forming the undergrowth; the mode of branching shown by the tree when growing with others in a clump or in a wood, and that shown by the same kind of tree when growing by itself in an open situation; the differences in size and in texture of the leaves well exposed to light, and of those growing in shade; the tendency of the leaves on each twig to form a "leaf-mosaic" (*i.e.* to vary in size and shape so as not to shade each other); the structure of the winter-buds, and the various ways in which the young leaves are folded up and protected; the seedlings, which may often be found under the trees. Refer to other parts of the book where the buds, leaves, flowers, fruits, etc., of these trees have been mentioned, and note the following points: (1) The general form and appearance as determined by the mode of branching, direction of the branches, and the character of the foliage. (2) The nature of the situation and the character of the soil in which each species apparently thrives with the greatest luxuriance. (3) The general effect of each kind of tree on the appearance of the landscape. (4) The thickness of the trunk as compared with the size of the tree, and the character of the bark. (5) The time of the appearance of the leaves, the form of the leaf, and the arrangement of the veins. (6) The time of flowering and the nature of the flowers. (7) The nature of the fruit and seed and the mode of dispersal. (8) The germination of the seed and the form of the seedlings, especially with regard to the cotyledons.

The following is a list of our principal forest trees, with a few of their distinguishing characteristics:

359. **The Pine** (fig. 187) may be known by its tall straight stem; long needle-shaped leaves, which are evergreen, and arranged in clusters of two, three, or five, with a sheath of chaff-like scales at the base of each cluster; and by its woody cones, the scales of which are thickened at the top. The Pine flowers in May and June. The flowers are unisexual, and both occur on the same tree. The male cones are clustered round the lower part of the

young shoots, and the flowers consist of overlapping anthers. The female cones are single or in clusters at the apex of the shoots, and consist of overlapping scales, each bearing two ovules. The latter develop into woody cones, which do not ripen until the autumn of the second or third year after flowering, and, when ripe, the naked winged seeds readily become detached from the woody scales. The Pine tree is of gregarious habit, forming immense forests in some regions. At high elevations it becomes a mere shrub. It produces very valuable timber, and also large supplies of wood tar and turpentine.

Fig. 187.—The Pine, showing Cones.

Fig. 188.—The Larch, with Cones.

360. **The Larch** (fig. 188) is also a gregarious cone-bearing tree. Its stem is very straight, and its drooping branches give it a pyramidal form. The leaves are needle-shaped, at first in tufts, and then separated by the growth of the shoots. They are small and narrow, and arranged in two rows where they are not tufted. The female flowers are in small, erect, egg-shaped cones, the woody scales of which are not thickened at the tip. The Larch provides valuable timber and turpentine; the bark is used for tanning. Unlike other conifers, it is deciduous, not evergreen.

361. **The Yew** (fig. 189) is an evergreen tree with a massive trunk and spreading branches. The narrow, dark green leaves are shining above, slightly curved, and are thickly set on opposite sides of the branches. The male and female flowers are produced on separate trees, on the under side of the twigs. The male flower consists of a scaly bud with a tuft of stamens projecting above its summit; the female flower does not produce a cone, but somewhat resembles a small acorn in form, and develops into a red cup-like fruit, containing a small nut, the top of which is exposed. The wood of the Yew is hard, with fine and close grain, and is also very flexible and elastic.

Fig. 189.—The Yew, with Fruits.

362. **Gymnosperms**. The Pine, Yew, and Larch belong to the lower of the two great divisions of Seed-plants, the *Gymnosperms*, in which the seeds are freely exposed, not enclosed in a seed-vessel (ovary) as they are in the higher and by far the larger division (Angiosperms). Many other Gymnosperms are cultivated in this country (Firs, Monkey's Puzzle, Cypresses, etc.), but the only native (*i.e.* not introduced in historic times) plants of this division are the Scots Pine, Yew, and Juniper. The Juniper is a shrub with prickly leaves and black fleshy fruits; it grows largely on chalk hills.

363. **The Poplar** (see pp. 294–6). The various species of Poplar may be known by the tremulous character of the leaves, due to the flattening of the stalk in a plane at right angles to that of the blade. They are rapid-growing trees, generally thriving best in moist situations; and, as a result of the rapid growth, the wood is so soft and of such loose texture that it is employed only for the making of packing-cases and other rough work. The Poplar flowers in March

and April, before the leaves appear. The male catkins are long, pendulous, and of a dark red colour; and the female catkins are conspicuous for the cottony down which envelops the fruit. The scales of the flowers are jagged at the extremity—a feature which serves to distinguish between the flowers of the Poplar and those of the allied Willows. The species most commonly met with in our country are (1) *The Lombardy Poplar*, distinguished by its slender and almost perpendicular branches; (2) *The Black Poplar*, with spreading branches; (3) *The White Poplar*, known by the white cottony down on the under side of the leaves; and (4) *The Aspen*, the leaves of which are nearly circular, smooth on both sides, and more tremulous than in the foregoing species.

364. **The Willow** (see pp. 294–6), as already stated, is allied to the Poplar. It is characterised by the same rapid growth and consequent softness of its wood, and by its still more strongly marked water-loving propensity shown by its frequent occurrence along the banks of streams. Its leaves, which are long and narrow, have the same downy under-surface so characteristic of most of the Poplars; and the seeds are similarly covered with a cottony envelope. The flowers appear in April and May, and, unlike the flowers of the Poplar, produce abundance of nectar. The *White Willow* may be distinguished by the silky whiteness of the under side of the leaves; and the *Crack Willow* by the extreme brittleness of its branches, which break off readily, when bent, close to the trunk. The *Osier*, the young stems of which are so much used for the manufacture of baskets, is a species of Willow. The *Goat Willow*, also known as the *Sallow*, may be known by the purplish-brown colour of its branches, and the large broad leaves, which are wavy at the edge. Some of the Willows are very small. In both Poplars and Willows there is abundant vegetative reproduction (see Art. 325) by suckers. In Poplars the terminal bud persists, producing a long main axis ("excurrent habit"); in Willows the terminal bud usually dies off, growth being carried on by lateral buds ("deliquescent habit").

365. **The Oak** (see fig. 190). This tree, so well known by its contorted branches, sinuate leaves, and cupuled fruit, need hardly be described. The small greenish flowers should be looked for in April and May. The male flowers are in pendulous catkins, with several stamens surrounded

Fig. 190.—The Oak, with Flowers.

by narrow scales. The female flowers are arranged singly or in small clusters, each being surrounded by overlapping scales that eventually form the cupule of the fruit. The tree furnishes very valuable timber, which is largely used for shipbuilding. See Fig. 152.

366. **The Sweet or Spanish Chestnut** has long, oval, toothed leaves, which remain on the tree till late autumn, when they assume a rich golden colour. The flowers are produced in long spikes during July, the male flowers being situated on the upper parts of the spike, and the female flowers near the base. The former soon wither and fall, while the latter develop into spiny husks, lined by silky hairs, and each containing from two to five pointed nuts, some of which do not fully develop. The fruit is ripe in September, and falls in October, when the cupule splits and exposes the nuts. The young wood of the Chestnut is tough, and is used for various purposes; but the older wood is too brittle to be of much service except as fuel.

367. **The Beech** (see fig. 191) is a large and handsome tree, especially when it grows on chalk hills. Its oval leaves are readily distinguished by their smooth surface and hairy margins. The flowers of the Beech are very similar to those of the Oak, and appear about the same time. The fruit consists of triangular nuts, enclosed in a spiny husk (cupule). The wood is far inferior to that of the Oak, but is used for quite a variety of purposes. See Fig. 151.

Fig. 191.—The Beech, with a Fruit.

368. **The Hornbeam** is usually much smaller than the Beech, and is most commonly seen in hedges, but its leaves and flowers resemble those of the Beech, though the former are not shiny, and are doubly serrated. The male flowers are in dense cylindrical catkins, and the female flowers in loose catkins. The fruit has one seed, and is enclosed in a lobed bract (fig. 192), which enables it to be carried by the wind. The wood is heavy and close-grained, but is not much used on account of its tendency to split.

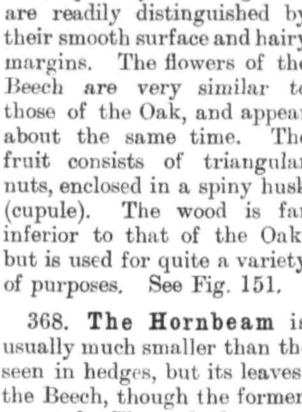

Fig. 192.—The Hornbeam, with Cluster of Fruits.

369. **The Birch** is easily recognised by its slender, drooping branches, light foliage, and white flaky bark with conspicuous transverse lenticels. Though a slender tree, it thrives in bleak situations. The leaves are rhombic in shape and doubly serrated. Each scale of the female catkin bears three flowers; the fruits are winged achenes. See Figs. 149, 150, 167.

370. **The Alder** is a smallish tree, growing chiefly beside streams. The young parts are sticky; leaves broad ovate, toothed (often also lobed), not hairy (cf. Hazel). The catkins are rather like those of the Birch, but the female catkin persists and becomes woody, like a Pine cone. The fruit-wall is spongy, and enables the fruit (containing one seed) to float on water for some time.

371. **The Hazel** is a small tree, rarely over 20 ft. high, and usually grows in hedges and copses. Its leaves are broadly ovate, doubly toothed, coarse and downy (with short hairs). The male flowers are borne in the axils of bracts on a long, hanging catkin; the female flowers are in pairs in the upper bracts of a small bud-like catkin, from the top of which the red stigmas project. The fruit is a nut, invested by a leafy cupule. The wood is of good quality, tough and elastic, and is largely used in making small articles; it also yields good charcoal (Figs. 146–8, 168).

Compare the characters of Fagaceae (Oak, Sweet Chestnut, Beech) and Betulaceae (Hornbeam, Birch, Alder, Hazel) in Appendix III. See also Ch. VI., pp. 296–8.

372. **The Elm** (fig. 193). There are two species of Elm in Britain, each varying a good deal in habit and shape of leaves. The Scotch, Wych, or Mountain Elm is thoroughly naturalised in this country; its trunk reaches a girth of 50 ft.; its leaves are from 3 to 6 in. long and 3 in. broad; the seed is in the centre of the winged achene. The Common Elm reaches the same height, but the trunk-girth rarely exceeds 20 ft.; its leaves are smaller; the seed is above the centre of the achene. In both cases the bark is rugged; the leaves simple, pointed, serrated,

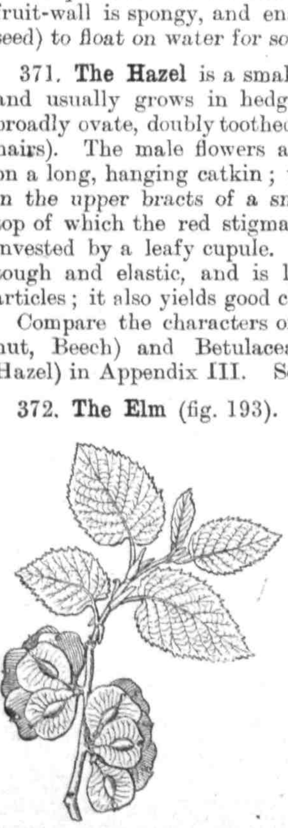

Fig 193.—The Elm, with Clusters of Fruits.

unequal at the base, with a rough surface. The flowers (*March, April*) are in dense clusters, purple-brown, and appear before the leaves. A little later the thin winged fruits fall in such abundance as to cover the ground where Elms are growing. The seeds of the Common Elm are said never to germinate in Britain. In both species the roots send up suckers, especially when cut, thus bringing about vegetative propagation. The timber is tough, and, being very durable under water, is largely used in building boats, etc.

The Elm is closely allied to the Nettle and Hop Families (see Appendix III., Urticales).

373. **The Lime.** This tree (fig. 194) grows wild in a few of the southern counties, and is consequently sometimes supposed to be a native; but this is doubtful, since the seeds do not germinate in uncultivated soil. It does not flourish well in the

Fig. 194.—The Lime—Leaves and Flowers.

north. The leaves are heart-shaped, with serrated edges. Its flowers, which bloom in June and July, have five sepals, five petals, many stamens, and a five-celled ovary with two ovules in each. They are of a greenish yellow colour, and have a long leaf-like bract attached to the axis of the inflorescence (a cyme). They are also very fragrant, and produce abundance of nectar, and are consequently very attractive to insects. The fruits are nuts, and the persistent bract forms a wing which aids in their dispersal by wind. The inner bark or bast is in great demand for binding, mat-making, and upholstering; and the wood, being soft and close-grained, is largely used by turners.

374. **The Sycamore.** The leaves of this tree (see fig. 195) are usually large, five-lobed, with edges unequally serrate and a palmate venation. The flowers are green, arranged in pendulous racemes, and appear in May and

Fig. 195.—The Sycamore, with Flowers.

June. The wood is used largely for furniture and toys, as well as for the preparation of charcoal. In Scotland this tree is popularly known as the Plane tree; the real Plane is quite different in its flowers and fruits.

375. **The Maple** is much smaller than the sycamore, and is most commonly seen in hedgerows. It closely resembles the sycamore in the character of its leaves, flowers, and fruit, but the leaves have crenate instead of toothed edges, and the floral racemes are erect. The leaves are also rendered conspicuous in the autumn by their rich golden and purple tints.

376. **The Horse-Chestnut**, though so common in our country, is not indigenous to it. It is so readily distinguished by its large compound leaves (fig. 196) with seven radiating leaflets, that a description for purposes of identification is hardly necessary. Even in winter it may be easily known by its dark heavy branches and large gummy buds, and in the flowering season its erect conical clusters of large white flowers, dashed with pink and yellow, offer a grand spectacle. Although the flowers are not perfumed, they are visited by numerous insects. The fleshy and prickly fruits mature in September, and fall to the ground

and split open in the following month. Each fruit contains one or two seeds (often called "nuts," though of course quite

Fig. 196.—The Horse-Chestnut—Leaf, Flowers, and Fruit.

different in nature from the nuts of Sweet Chestnut, Oak, and Hazel, which are fruits). The tree grows very rapidly, hence the wood is soft, and of little value except as fuel.

377. **The Ash** (fig. 197) is common in woods and hedges, but has generally been planted. It is a fairly tall tree (50 to 80 ft.) with pale bark, stout twigs, and black buds. The leaves are in crossed pairs, each leaf being compound, with about five pairs of opposite leaflets and a terminal one. The leaflets are sessile, long, and narrow, with serrate edges. The *flowers* * are very small and simple in structure, having neither calyx nor corolla. They are of a dark purple colour, and as they appear in April, some weeks

Fig. 197.—The Ash, with a Cluster of Fruits.

* See Art. 286, p. 299.

before the late foliage, they are very conspicuous at the tips of the branches. The fruits are winged, and grow in dense clusters. The wood is highly valued on account of its toughness.

QUESTIONS ON CHAPTER IX.

1. Distinguish between a species, a variety, a natural order, and a genus, illustrating your answer by reference to three examples of each. Can you exhibit the relations of the four in a diagrammatic form ?

2. Name the three commonest English species of Buttercup. Describe any one of them as fully as possible, and point out exactly the characters in which the other two differ from it and from one another. Do you find them growing in similar or in different places ?

3. What is meant by (*a*) Plant Ecology, (*b*) Struggle for existence, (*c*) Survival of the fittest, (*d*) Natural selection ?

4. Describe the chief modes of perennation in perennial plants.

5. Explain the terms "monocarpic," "polycarpic," "ephemeral," and give examples of each.

6. For what different purposes do you consider that a plant requires to be supplied with water ? How are some plants able to withstand long-continued drought uninjured ? Give instances of such plants.

7. How does the climate inside a greenhouse differ from that without ?

Name plants whose natural habitats are in climates (*a*) drier, (*b*) wetter, (*c*) hotter, (*d*) colder than that of an English garden. What arrangements would you make if you had to try to grow these various plants in England ?

8. The island of Singapore produces more than 2,000 native species of flowering plants ; the Isle of Wight (about equal in area) some 800 ; an equal area in the Egyptian Desert, less than 200. To what causes would you attribute these striking differences ?

9. Mention the six most troublesome weeds in any garden with which you are well acquainted. Explain carefully, so far as you can, the reasons why each is specially troublesome.

10. Mention any observations you may have made on the flora of ground that has been turned over but not planted—*e.g.* railway embankments, fallow fields, garden beds. Can you give a list of plants growing in such places, and account for their presence ?

11. Give several examples of groups of plants which grow together in the same habitat or locality and flower at about the same season. Why do these plants grow side by side, what causes bind them to special localities, and why do they flower simultaneously ?

12. Suppose you were asked to write a report on the vegetation of some particular acre of ground (heath, common, meadow, marsh, woodland, moor, or hillside), how would you set about the task? What would you try particularly to find out? What observations and notes would you make? How much time would you wish to be allowed for the inquiry?

13. Show, by reference to alpine plants, to the carpet of spring flowers in woodlands, to flowers of foreign origin in English gardens, to the lack of flowers in hayfields after July, and by other illustrations, that the competition of neighbouring plants is one important condition of plant-life.

14. Name several different species of plants that you have found at the seaside and not inland. State exactly where and how each was growing, and mention any characters possessed by each that you think fitted it to its particular circumstances.

15. Give an account of the vegetation of sand-dunes in any region you may select, and point out the special adaptations exhibited by the plants to their surroundings.

16. Write a list of plants which you have found on moorland walks. What peculiarities of leaf-structure have you observed in any six of these? How does the possession of such peculiarities profit the plant? What was the nature of the soil on which the moorland plants grew?

17. What wild flowers have you found growing along the margins of lakes, ponds, and rivers? Distinguish those which grow with their stems (*a*) wholly in the air, (*b*) partly in air and partly in water, (*c*) wholly submerged. Show by sketches what you mean by the zones of vegetation along the water margin.

18. Write a list of any plans which you have found growing with their leaves submerged in water. How do such plants obtain the gases which they require for respiration and photosynthesis? Describe the surface structure of a leaf (*a*) in a land-plant, (*b*) in a water-plant.

19. Write an account of the vegetation you might expect to find growing on a swampy moor, and indicate any points in which the plants appear to be structurally adapted to such an environment.

20. Name three English trees with which you are thoroughly familiar. Describe the habit, branching, buds, bark, leaves, flowers, and fruit of each. In what sort of situation would you expect to find each growing? Make your descriptions so clear that the trees could be easily distinguished and identified.

21. What special anatomical peculiarities would you expect to find in water-plants? Explain how the structure you describe is connected with their conditions of life.

22. Enumerate the more common plants which you have found growing in a marsh.

begin active growth and division as soon as they meet with suitable conditions. Other kinds of Bacteria easily obtained are the blood-red and purple forms, which grow on soaked bread placed under a bell-jar, and the branched thread form (*Leptothrix*), which causes decay of the teeth, and can be obtained by scraping the teeth near the gums.

Nearly all Bacteria are either parasites or saprophytes, but a few seem able to make use of carbon dioxide, while others can fix free nitrogen. Most of them require free oxygen, but some can only grow in the absence of oxygen. Well-known examples of changes set up by Bacteria are the souring of milk; the conversion of alcohol into acetic acid; putrefaction of proteids, accompanied by the setting free of offensive gases (ammonia, sulphuretted hydrogen, phosphoretted hydrogen).

The micro-organisms present in soil include, besides Bacteria, various Moulds, Yeasts, and the threads which form the vegetative body of the higher Fungi.

380. **Yeasts** resemble Bacteria in being very simple plants, consisting of cells which occur either separately or in branching rows. The changes caused by Bacteria in milk, in alcohol, and in proteids are often called fermentations. Yeasts carry on alcoholic fermentation, splitting up sugars into alcohol and carbon dioxide; various other substances are also formed in the process. The most familiar kind of Yeast is Beer Yeast, or Brewer's Yeast; another kind sets up fermentation in grape-juice in the making of wines. In brewing, the grain (barley) is allowed to germinate until the starch (stored in the endosperm) is largely converted into sugar, then the sprouting barley is killed by heat, and the sugar extracted by water and Yeast added to the extract. If some Yeast is rubbed up in water to form a paste, and a little of this is added to a solution of sugar, the liquid soon becomes turbid, bubbles of gas (carbon dioxide) rise to the surface and form a froth, and the liquid loses its sweetness and smells of alcohol. The turbid sugar-solution is found to contain an enormous number of Yeast-cells, some floating singly while others are connected in chains.

The process of multiplication goes on rapidly, and may be watched under the microscope. When the Yeast is active, certain of the cells may be seen to produce little globular buds which grow till they reach the size of the parent cells. These generally produce other buds while still attached to the original cell, and the progeny may be set free as independent organisms when fully grown, or they may remain attached to their parent cells, and form branching chains (fig. 198).

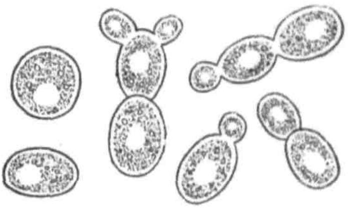

Fig. 198.—Yeast Cells, highly magnified.

Another method of multiplication may be observed in the case of Yeast-cells. The protoplasm of a cell divides into distinct parts, usually four in number, and a cell-wall is then formed around each. Eventually the wall of the parent cell dissolves away, and the little masses within are set free as *spores*. This is met with only under unfavourable conditions, more especially when there is an insufficiency of food-material—*e.g.* when Yeast-cells are grown on the cut surface of a Potato, or on moist plates of plaster-of-Paris, or left in a neglected condition in a jar. These spores retain their vitality for a considerable time, even when perfectly dry. They are easily wafted about in the atmosphere, and develop into active Yeast-cells whenever they reach a suitable nourishing fluid.

It has been shown that while the Yeast-cells thrive best in the presence of oxygen—*i.e.* while the growth and division of the Yeast-cells are most rapid in this condition—the weight of sugar transformed into alcohol and carbon dioxide *per unit weight of Yeast* is much greater in the absence of oxygen; and that, when oxygen is abundantly supplied, *relatively* little alcohol is produced.

Exp. 365. Rub up some dried Yeast in water to make a paste, and stir a little of the paste into sugar-solution contained in three glass jars (a tablespoonful of sugar to a pint of water). Place one jar in

the light and another in the dark, keeping both in a warm place; keep the third jar cold by setting it into ice, and place it in the dark. Note that the growth of the Yeast, as shown by the cloudiness of the liquid, liberation of bubbles, and formation of alcohol, is most active in the jar kept in a warm place in darkness.

Exp. 366. Test the gas given off by sugar-solution in which Yeast is growing, by lowering a lighted match or taper, or a glass rod with a drop of lime-water on its end, into a jar; or place some Yeast containing sugar-solution in a flask fitted with a cork and bent tube dipping into lime-water.

Exp. 367. The alcohol produced may be recognised by smelling and tasting the fermenting sugar-solution from time to time, or by warming the liquid in a test-tube or flask fitted with a straight piece of glass-tubing until the alcohol-vapour given off can be ignited with a match.

381. **The Meaning of Fermentation.** All plants must have a supply of energy for carrying on their metabolic processes, and for the performance of internal and external work. In most plants the necessary energy is liberated by oxidation, to which the term of **aerobic respiration** is usually applied, and most plants die if deprived of oxygen. *Some* plants, however, can obtain a supply of energy in another way, which does not necessarily involve any consumption of oxygen—namely, by breaking down the complex substances of which their food is composed, which process is usually termed **anaerobic respiration.**

The term fermentation is a popular one, and is applied to cases of anaerobic respiration when the products of the latter are unusually conspicuous or abundant. The tendency to produce a ferment is so strong in the case of the Yeast-plant that its production does not entirely cease even in the presence of oxygen, when the plant can obtain all the energy required by aerobic respiration. This is the explanation of the *relatively* greater activity of the process of fermentation in the absence of oxygen.

It is probable that all processes of fermentation are set up by substances secreted by the living protoplasm—*i.e.* by *ferments* of various kinds. The ferment which sets up alcoholic fermentation of sugar-solution can be extracted from crushed Yeast-cells, filtered, and can bring about exactly the same changes as the Yeast-cell itself. This

ferment is called *zymase*. If Yeast is added to cane-sugar, it secretes a ferment (invertase) which converts the cane-sugar into grape-sugar ; this change appears to be necessary before alcoholic fermentation can take place. Ferments have been extracted from some Bacteria, and there is little doubt that all bacterial actions are due to their secreting special ferments. See pp. 74–7.

382. **Moulds,** which belong to several groups of Fungi, resemble Bacteria in causing decay. Moulds occur on all kinds of organic substances—*e.g.* jam, bread, cheese, horse-dung, damaged fruit, and vegetables, and fine growths of various Moulds can be obtained by moistening any of these substances and covering them over. Three very common Moulds obtained in this way on moist bread or horse-dung are Mucor, Eurotium, and Penicillium. In each case the vegetative part of the Mould, called the *mycelium*, consists of interlacing threads which branch in, and on the surface of, the organic substance on which the Mould is growing. From the mycelium special branches grow up into the air, and at the ends of these branches numerous spores are produced. In *Mucor*, the end of each erect aerial branch swells up, and the spores are formed inside the swelling, being set free when its thin brittle wall breaks open (fig. 199). In *Eurotium*, the spore-producing branch swells at the top, but the spores are formed in chains on the surface of the swelling (fig. 200). In *Penicillium*, the end of the spore-producing branch divides into several parts, each of which divides again and gives rise to rows of spores.

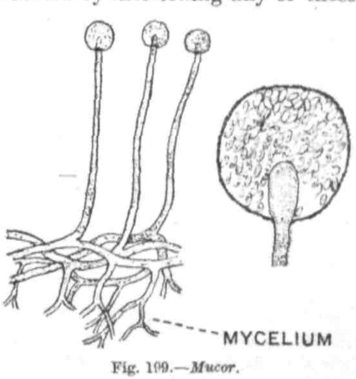

Fig. 199.—*Mucor*.
A, A portion of a mycelium bearing reproductive branches ; B, a single reproductive chamber containing the "spores."

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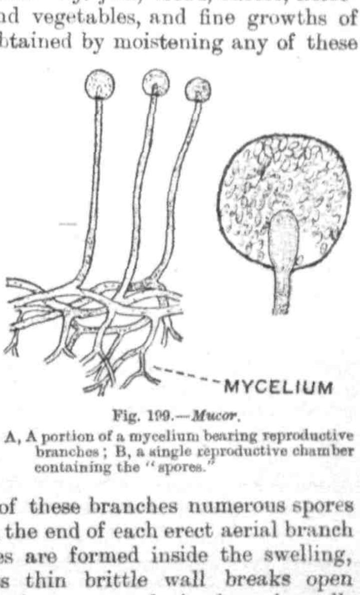

Fig. 199.—*Mucor*.

A, A portion of a mycelium bearing reproductive branches; B, a single reproductive chamber containing the "spores."

In *Mucor*, the spore-masses are black when ripe, in *Eurotium* and *Penicillium* they are bluish-green. In all cases the spores are very light, so that they can remain for a long time in the air, and germinate whenever a suitable organic substance is met with. In all cases, too, the Mould can produce spores in a different way when conditions become unfavourable—*e.g.* when the food supply becomes exhausted. From branches in or on the organic substance, special spore-cases are formed, containing thick-walled spores which are very hardy, like the spores of Bacteria and Yeasts, and are larger than the ordinary spores, so that they contain more food, and on germinating give rise to a more vigorous mycelium.

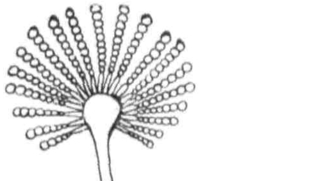

Fig. 200.—Eurotium. Mycelium and Spore-producing Branch.

383. **Higher Fungi**, like Mushrooms, also have a mycelium of branching and interlacing threads. The mushroom (fig. 201) is a saprophyte. It lives on decomposing organic substances (humus) in meadows and other localities. The part of the fungus which is seen above ground—the part which is called the mushroom—is only the reproductive structure. This is developed on a delicate filamentous mycelium, which ramifies through the soil and absorbs the organic compounds on which the fungus lives. The so-called "mushroom-spawn," so largely used in the cultivation of mushrooms, consists simply of compacted blocks of well-manured soil containing a tangled mass of threads. The part above ground consists of a stalk and a cap on the lower

surface of which are the gills. The spores are produced from the cells covering the gills, and are chocolate-brown when ripe.

Fig. 201.—The Mushroom.

384. **The Work of Bacteria and Fungi in Soil.** Fungi, Moulds, and Yeasts act on various organic substances in the soil, using part at least of these substances to build up their own structures, and when the latter decay the material left is more susceptible to the action of nitrifying Bacteria than were the original organic substances. The mycelium of Moulds and other Fungi breaks up dead leaves and other vegetable matter in soil, and it appears that Moulds have a large share in converting the nitrogen of proteids into ammonia, especially in manure-heaps, humus (leaf-mould), and very peaty soils.

Various Bacteria have the power of converting proteids into ammonia, but the further changes from ammonia to a nitrite, and from nitrite to nitrate, are each the work of one particular micro-organism. In the change from organic

nitrogen to ammonia, oxidation of carbon occurs in the organic substances acted on, and this production of carbon dioxide probably supplies the necessary energy. The other two stages in the process of nitrification, ammonia to nitrite and nitrite to nitrate, are, of course, processes of oxidation, and it has been found that the Bacteria which cause these changes can do their work in solutions containing no organic matter. These particular Bacteria can obtain their carbon from carbonates or from carbon dioxide, and they do this without the aid of light, the necessary energy being obtained by the oxidation of the nitrogen. Bright light stops the action of these Bacteria and eventually kills them ; this is true of nearly all Bacteria.

Serious loss of nitrates often occurs in manure-heaps that have been kept too long, and also in soil to which too much farmyard manure has been added. This loss is due to denitrification, which is the work of another kind of Bacteria, differing from the nitrifying kinds in acting only in the absence of oxygen. The denitrifying organism oxidises organic substances by reducing nitrates, nitrogen being set free, so that the conditions under which this organism carries on its destructive work are (1) presence of large amounts of easily oxidised organic compounds, (2) absence of oxygen.

A most important process set up by certain soil Bacteria is the fixation of free atmospheric nitrogen and the formation of nitric acid. According to some observers, the nitrogen-fixing organism can only work in the absence of oxygen, so that it must have other Bacteria to help it by removing the oxygen from the soil. As is well known, a fertile soil soon becomes exhausted of plant-food, especially of nitrogen, when successive crops are grown in it, and the crops become poorer and poorer until manures are supplied. The most important of all manures is nitrate of soda, and there is strong reason to believe that the deposits of this substance, found chiefly in rainless districts of South America, have been produced by the work of Bacteria of the nitrogen-fixing kind. These deposits have doubtless accumulated during millions of years, the nitric acid produced by the Bacteria combining with soda present in the

soil, and the soluble nitrate thus formed being preserved from loss by the extreme dryness of the climate. These valuable deposits are being rapidly used up, while the rate at which the nitrogen-fixing organisms work is of course very slow, and the conditions necessary for the production of thick beds of nitrate—*e.g.* a practically rainless area of desert—are only found in a few parts of the world. Nitrate of potash occurs in deposits in certain rainless regions of India. Though the nitrogen-fixing Bacteria occur everywhere in fertile soil, the nitrates produced are soon used up by plants or washed out by rain-water. Long ago, Cavendish discovered that when an electric discharge is passed through air to which oxygen is added, brown fumes of oxide of nitrogen are produced—*i.e.* the nitrogen is oxidised or burnt up, and the resulting oxide on being dissolved in water gives nitric acid. Cavendish added soda to the acid solution, and on evaporating the liquid obtained crystals of nitre, hence the name nitrogen or "nitre-former." This discovery of Cavendish has recently been made the basis of a process for making nitric acid from the nitrogen of the air on a large scale.

In woods and plantations, the upper layers of the soil consist of decaying matter (humus), and, besides containing myriads of Bacteria, are permeated with the threads of various Fungi, all at work digesting (by means of ferments) the dead leaves, twigs, etc., which are riddled by these threads. Next to Bacteria, the thread-forming Fungi are the most important agents in the decay of dead plant-tissue. Some Mosses, which grow luxuriantly in damp woods, help in the breaking-up of leaves, dead wood, etc., by sending their root-threads into the dead cells, boring through the cell-walls just as Fungus-threads do, and thus living as partial saprophytes. It would appear that most woodland plants are enabled to make direct use of the organic matter in the soil. Fungi do this by means of their threads, but most higher plants require the aid of a "fungus-servant" (mycorhiza). Besides this, woodland plants get the benefit of the nitrates produced by the work of Bacteria and Fungi, which are absorbed by their roots in the ordinary way.

385. **The Work of Animals in Soil.** Various animals help in the breaking-up of decaying leaves and other vegetable matter, either (1) by burrowing in the soil and loosening it, so that oxygen is more rapidly supplied to Bacteria and Fungi, at the same time making it easier for fungus-threads and roots to spread in the soil; or (2) by living on the organic matter and passing it through their bodies. The most important work of this kind appears to be done by insects and by earthworms.

386. **Work done by Insects.** Various flies and beetles feed on decaying organic matter in the soil, as well as in manure-heaps, in decaying wood, and on sewage-farms. In the last case, some flies which feed on the sewage-matter play an important part as "scavengers," passing decaying matter through their bodies, and thus making it harmless, and assisting the scavenger-work of Bacteria. The insects which live on decaying matter usually lay their eggs in it, so that their young (larvae) may be provided with abundant food.

387. **Work done by Earthworms.** Darwin says: "The plough is one of the most ancient and most valuable of man's inventions, but long before he existed the land was regularly ploughed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world as have these lowly organised creatures." Every one is familiar with the "casts" formed by earthworms on the surface of the soil in gardens and fields. Worms line their burrows with fragments of leaves, and feed on the decaying organic matter in the soil, which they swallow in large quantities, and eject in the form of casts. They live in their burrows during the day, and emerge at night for food; in very cold or dry weather they are inactive. About ten tons of earth in each acre of ground pass annually through the bodies of earthworms, in places where they are numerous. Worms help to expose fresh soil at the surface, and to sift and mix the soil; they cover up seeds lying on the surface, thus giving the radicle a leverage for its downward growth as

well as keeping the seed moist; their burrows help roots to penetrate the ground. Their most important work, however, is that of passing through their bodies vegetable matter, which they convert into "vegetable mould" (humus) and bring to the surface.

Exp. 368. Look for worm-casts on the soil. Keep worms in a pot, keeping the soil fairly moist, and covering the pot with a sheet of glass; feed them on cabbage-leaves. Cover the glass with black paper or cloth; on removing this you will often see the worms at their work. How long is an earthworm? Where is it greatest in girth? What differences are there between the front ("head") end and hinder ("tail") end? How does the worm move? Notice that each segment or ring carries four pairs of bristles; these bristles, forming four longitudinal rows along the body, help the worm in its movements. Notice the peculiar thickening seen in all except young worms; this "saddle" secretes the egg-case, in which the very young worms are hatched. Of what colour is the skin, and how does it differ on the upper and lower sides? Notice the blood-vessel along the back; in what direction does the blood flow in this vessel? Kill a worm by putting it into alcohol; cut it open, and notice the soil in its alimentary canal.

QUESTIONS ON CHAPTER X.

1. "The life-actions of Bacteria are regarded as being largely responsible for the circulation of nitrogenous compounds in the soil." Criticise and explain this statement.

2. Describe the structure and mode of growth of Bacteria. What changes do Bacteria set up in dead organic matter?

3. Describe the structure and mode of life of Yeast, including an account of alcoholic fermentation.

4. Describe the growths that occur on a piece of bread which is kept moist and covered by a bell-jar. Which of these growths are due to Moulds, and which to Bacteria?

5. What is meant by Anaerobic Respiration? Discuss the question with respect to green plants and Bacteria.

6. Describe the work done in the soil by (*a*) insects, (*b*) earthworms.

CHAPTER XI.

PRINCIPLES AND PROBLEMS OF PLANT BIOLOGY

388. Morphology and Physiology. Plants may be studied from different points of view, which constitute different divisions or departments of **Botany** or **Plant Biology.** One of these departments is called Morphology, which has a much wider scope than is implied by the literal meaning of the word ("study of shape"). Morphology deals with the external form, internal structure, relative positions, and mode of development of the different parts of the plant-body. In our study of any particular plant, we first give our attention to the external features, and find that the plant consists of certain well-defined parts, or members—roots, stems, leaves, flowers, fruits; also that these parts have practically the same forms in all plants of the same species, while they differ more or less widely from those of other species; that the stem branches, and that the branches have a definite position in relation to the leaves. By comparing the relative positions of the members in our type with those in other plants, we could draw up a classification of plant-members. This study, dealing with external forms and relative positions of plant-members, is called **External Morphology.** We might then wish to gain some knowledge of the internal structure of the various members. For this purpose we should make various sections of root, stem, leaf, etc., and examine them with the naked eye, simple lens, or microscope. This study of **Internal Morphology** may be termed **Anatomy** if only the coarser features are examined with the naked eye; **Histology** if the microscope is used. Morphology, then, has regard only to the form and structure of plants, and pays no attention to the functions which they perform.

We might, however, carry our morphological studies further than this. Instead of examining our plant at any one particular stage of its existence, we might study the form and structure of the various parts through all the stages of the plant's growth, observing all the changes which take place. Beginning with the seed, we could make out the parts of the embryo plant contained in the seed; we could notice the gradual growth of root and stem, the formation of foliage-leaves, the origin and growth of branches; finally, we could study the flower, and follow the morphological changes which lead up to the formation of another seed. This is a study of **Development.** Another morphological study is **Classification.** It is based on Comparative Morphology and Development. Here the forms and structures of plants in all stages of their life-histories are studied and compared, and according to the resemblances and differences perceived the plants are arranged or classified.

In the study of **Physiology** we regard the plant from a different point of view. Physiology deals with the various processes that are necessary for the life and growth of the individual plant, and for the perpetuation of the race. In Physiology, form and structure are of secondary importance, and need only be studied in so far as they throw light on the functions of the various organs. We have to deal with such questions as: Whence, in what form, and by what means does the plant obtain its food-materials? How does the plant grow, and whence does it derive energy? How are growth and other life-processes affected by heat, light, and the environment generally?

For instance, we know by the study and comparison of different plants provided with tendrils that the latter may be modified leaf-structures, or branches, or inflorescences, etc. What a tendril *is*, is a morphological question. On the other hand, what the tendril *does*, is a physiological question, involving the study of the tendril's sensitiveness to contact, etc., without reference to its morphology. Again, comparative morphology shows that reserve-food may be stored in various, more or less modified, organs—*e.g.* rhizome, bulb, corm, bulbil, tap-root, hypocotyl, adventitious root,

etc.; but the physiology of food-storage is simply the study of the processes by which food is manufactured, how and in what form it is transported, and how converted into its ultimate storage-form.*

389. Division of Labour. The lowest plants are of microscopic size, and have a very simple structure. For instance, in the green Alga, called *Pleurococcus*, each individual consists of a little bladder (cell), bounded by a firm wall of cellulose, and containing (1) a colourless, slimy, granular substance (protoplasm); (2) a central denser body (nucleus) which absorbs stains more deeply than the protoplasm; (3) just within the cell-wall several green disc-shaped bodies, the chloroplasts; (4) spaces filled with clear sap. In a unicellular plant like this, all the vital functions are of course carried on by the living substance of the cell. In *Pleurococcus*, reproduction is effected by the cell growing larger and dividing into two; the cells formed in this way sometimes hang together for a time before separating to form new plants. In another green Alga (*Spirogyra*), which is much easier to study on account of its larger size, we find that the plant begins life as a single cell (as of course all plants do); but by growth and repeated division it comes to form a row of cells placed end to end, all exactly alike in structure. Although *Spirogyra* is a multicellular plant, each cell lives an independent life, and carries on all the vital processes just as the single cell does in *Pleurococcus*. In the great majority of multicellular plants, however, the plant-body consists of cells and structures derived from cells (vessels, fibres), these units being connected to form the various **tissues**—*e.g.* parenchyma, sclerenchyma; the living cells are not isolated and independent, but are connected by very fine protoplasmic threads which pass through the intervening cell walls. The different parts of the plant-body take on different functions, and each part has a form and structure adapted to the performance of its own function or set of functions. Since these various functions are

* Parts which resemble each other in position and in mode of development—*i.e.* which agree morphologically—are said to be **homologous**; parts which have the same function are **analogous**.

carried on for the good of the plant as a whole, it is evident that in such a plant (*e.g.* the Bean) there is **division of physiological labour.** The distribution of functions involved in this division of labour may be termed **physiological differentiation**; the marking off of distinct parts to serve as the organs of particular functions is called **morphological differentiation.** It is obvious that physiological and morphological differentiation go hand in hand. In the lower plants there is little division of labour, but in passing from lower to higher forms we find the arrangements become more and more complex, and the division of labour correspondingly extensive. Speaking generally, we distinguish between lower and higher forms largely by the degree of differentiation and division of labour shown in each case.

Exp. 369. To obtain *Pleurococcus* for microscopic examination, scrape some of the green powder found on tree-trunks or palings on to a glass slip, add a drop of water, and cover. Notice the green cells, occurring singly or in small colonies. Treat with a drop of alcohol (to dissolve out the chlorophyll) and with iodine solution; look for the nucleus which stains deeply with iodine.

Exp. 370. Mount in water and examine with the microscope a small quantity of *Spirogyra*, a green filamentous freshwater Alga, commonly found in ponds and slow streams.* The filaments feel slimy, owing to a coating of mucilage on the surface. Notice the unbranched filaments, each consisting of a row of cylindrical cells, separated by cross-walls at intervals, and each containing one or more green spiral bands. With the high power notice (1) the smooth, colourless cell-wall; (2) the thin film of granular protoplasm immediately within the cell-wall, in which are embedded (3) the flat green bands, which have ragged edges, and show at intervals small rounded highly refractive bodies, the pyrenoids; (4) the large central cavity (*vacuole*) of the cell, containing colourless transparent cell-sap; and (5) the highly refractive spherical or lens-shaped nucleus in the centre of the cell. Stain some filaments with iodine, and observe that the pyrenoids have become dark purple or almost black, owing to the presence of crowded small starch-grains, and that the nucleus is connected with the outer layer of protoplasm by fine threads, each usually ending at a pyrenoid.

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* *Spirogyra* is supplied by Mr. Bolton, 25, Balsall Heath Road, Birmingham, at almost any time of the year, in shilling tubes. Any other material for practical botanical work, which may be difficult to obtain locally, can be bought from Mr. Bolton, or from the British Botanical Association, Holgate Nurseries, York.

Mount some *Spirogyra* filaments in water, place at one edge of the cover-glass a few drops of 5 per cent. solution of common salt, and while watching a filament, draw the salt-solution under the cover-glass by holding a piece of blotting-paper at the other side. Notice that the protoplasm shrinks from the cell-wall, as water passes by diffusion (osmosis) from the cell-sap in the vacuole into the salt-solution outside. Sketch the contracted or *plasmolysed* cell, then draw a little water under the cover in the same manner, and notice the cell return to its normal *turgid* condition.

Put some *Spirogyra* filaments in alcohol, and after a day or two notice that the spiral bands have become colourless, the green colouring matter (chlorophyll) having been dissolved by the alcohol, which also contracts or plasmolyses the cells.

390. Root and Shoot. In the ordinary erect type of higher plant, and in the seedlings of plants which later assume special modes of growth (rhizomes, corms, bulbs, etc.), the descending part of the plant-body, which serves to fix the plant in the soil and absorb water containing dissolved salts, is well marked off from the shoot whose tendency is to grow upwards towards air and light. The shoot is nearly always further differentiated into stem and leaves. The stem ends in a bud and bears leaves, lateral buds, and reproductive organs. The ordinary functions of the stem are to bear the leaves and keep them exposed in such a way that they may best carry on their functions and to give passage to various nutritive solutions passing between roots and leaves. According to the form and mode of growth of the stem, the plant may be creeping, trailing, twining, etc., herbaceous or woody; in the latter case usually **arborescent** (*i.e.* forming a tree or shrub). Modifications of the shoot, adapted to different kinds of habitat and different modes of life, are the runner (*e.g.* Strawberry, Houseleek, London Pride), sucker (Mints, Roses), bulbil, *i.e.* a bulb-like bud formed above ground (Lesser Celandine, some Lilies, Garlics, Grasses, etc.), rhizome, corm, bulb, stem-tuber, stem-tendril, stem-spine (thorn), cladode. The reproductive or floral region of the shoot is usually marked off from the vegetative or foliage region. Our conceptions of stem- and leaf-structures are drawn from a consideration of the vegetative region; they may be applied to some extent to the flower, but the essential parts of the latter—the

pollen-sac and the ovule—cannot be compared with any of the vegetative organs of the plant.

We have seen that there are various types of leaf-structure adapted for the carrying-on of different functions. The commonest of these types are foliage-leaves, scale-leaves, cotyledons, bracts, perianth-leaves, while leaf-tendrils, leaf-spines, phyllodes, pitchers, and other insect-catching leaves are adaptations of less general occurrence.

Roots, like shoots, have a form and structure adapted to their mode of life. In some cases roots are insensitive to gravity, but grow from the light (*e.g.* climbing roots of Ivy); in many tropical Orchids and Araceae they contain chlorophyll, and help in photosynthesis. Most roots, however, being buried in the soil, are not exposed to such a diversity of influences as are shoots; their environment being less complex and more uniform, they naturally show less variety in form and structure. Still, roots may take on special functions; they may act as store-places of nourishment, as climbing organs, etc., or may be more highly specialised as floats, tendrils, or spines.

391. Adaptation. We have already considered some of the adaptations of form and structure which are shown by plants growing in certain habitats (moors, salt marshes, etc.), but a little reflection will show that *every* plant must, in order to hold its own in the struggle for existence, be more or less completely adapted to its surroundings—in other words, every plant growing in its natural habitat must be sufficiently well equipped to survive in the competition for light, air, etc., which is continually going on between it and other plants of the same and of different species. This struggle for existence is naturally keenest in those localities in which the soil is fairly rich in plant-food, and which receive sufficient moisture, warmth, air, and light. It is easy to see why far more plants belonging to different species grow in open fields and roadsides, along hedge-banks and ditches, than in shaded woods and plantations, on moors or in salt-marshes. Mesophytes (p. 371) far outnumber the more extreme types adapted to special habitats in which the struggle for existence is less severe. On the other

hand, specialisation usually entails a loss of adaptability—*i.e.* a loss on the part of the plant of the power of accommodating itself to new surroundings. Hence highly specialised plants must usually conquer their surroundings in order to survive, and remain as "fixed" types as long as they can do this, but become extinct when subjected to adverse conditions.

392. The Plant's Equipment. We have seen that the plant-body is a machine made up of different parts performing different functions, and thus showing more or less well-marked division of labour. In studying the adaptation of plants to the external conditions in which they live, one is apt to concentrate attention on the special advantages possessed by certain plants and to neglect the great majority of plants which seem to show no striking biological adaptations. Yet a little observation and reflection will convince one that what counts in the struggle for existence is the whole equipment of the plant, not the possession of any single adaptive or advantageous feature. For instance, plants provided with specially good mechanisms for seed-dispersal are often apparently no more successful or widely distributed than allied plants which have not these particular mechanisms. Daisy and Milfoil (Yarrow) are two of the commonest plants in this country, though they are comparatively poorly equipped as regards seed-dispersal, since they differ from most British Composites in having no pappus. The same applies to other isolated advantageous characters possessed by certain plants, and not by other plants which are closely allied, or found in the same habitat, or equally successful as judged by their abundance and wide distribution.

393. Comparison and Correlation. In the study of Plant Biology you should always be on the alert to ascertain whether the differences in form and structure presented by different plants can be accounted for by differences in their mode of life and habitat. This study, which has already been dealt with in Chapter IX., requires not only a sound

knowledge of the morphology and physiology of plants. All the factors that make up the environment must also be taken into account. These factors fall into two main groups: (1) the **edaphic** factors, including the physical and chemical characters of the substratum—*i.e.* in most cases the soil; (2) the **climatic** factors, including temperature, rainfall, etc. You should carefully compare the different parts of the plants which are studied as "types." A grass, a Dicotyledonous herb (*e.g.* Broad Bean), and a tree might be studied to begin with; the erect herbaceous type may be taken first, and the other types compared with it.

We have already (pp. 131–2) compared in some detail the foliage-leaf and the cotyledon of the Broad Bean. You should draw up, in parallel columns, a comparison between the root and the stem, with reference to external form, colour, mode of branching, organisation of growing-point, position and arrangement of conducting and strengthening tissues, relative positions of wood and bast, position of first-formed vessels (protoxylem) in the wood, mode of secondary thickening, nature of response to gravity, light, moisture, and any other points that occur to you. Then try to discover, not merely by reasoning, but by observation and experiment, what biological advantage to the plant is derived from each of the differences noted.

Next consider the adaptations of the ordinary bifacial type of foliage-leaf. Its flattened form and its position are the most favourable for absorbing carbon dioxide and for catching light. The epidermis and cuticle prevent excessive evaporation, besides acting as a screen against undue heating and other ill-effects of strong light. Both palisade and spongy mesophyll cells, containing numerous chloroplasts, are adapted for assimilation. The palisade tissue is adapted to protect the chloroplasts from the effects of too bright light; when the light is diffused, the plastids are arranged chiefly along the upper and lower walls of the columnar palisade cells, but in strong light the protoplasm moves in such a way as to arrange chloroplasts along the side-walls of the cells with their edges (the chloroplasts are disc-shaped) presented to the light. The spongy-tissue, with numerous air-spaces communicating with the atmosphere by means of

the stomates, is equipped for carrying on the gaseous exchanges concerned in respiration, photosynthesis, and transpiration. The spreading veins, the larger ones projecting on the lower side of the leaf, while the smaller ones run between the palisade and spongy mesophyll, carry water (with dissolved salts) *to* the mesophyll cells and elaborated food (sugar, etc.) *from* them. The mesophyll cells are arranged more or less definitely in groups extending from the epidermis to the veins; this is clearly seen in most leaves with well-marked palisade mesophyll, the cells of the latter being arranged in a fan-like manner as seen in vertical section (see fig. 44), and the cells which converge towards the veins have been called "collecting" or "conducting" cells. The veins also serve in the best way to support the leaf; this supporting function is discharged especially by the larger veins, which have bands or cords of hard-tissue (sclerenchyma) below or above or in both positions.

Why are the leaves of most shade-preferring plants (*e.g.* Enchanter's Nightshade, Wood Anemone, Sanicle, Moschatel) devoid of hairs and more delicate in texture than those of plants growing in open situations? Why are the leaves of many plants growing in exposed places provided with a covering of hairs? On which side of the leaf is the hairy covering developed most, and why? Why are evergreen leaves (*i.e.* leaves which remain on the plant for two or more years) usually tough and leathery, with thick cuticle, a relatively small amount of air-space in the mesophyll, sunken stomata (few in number, and confined to the lower surface as a rule), and other xerophilous characters?

394. The Grass Type. Grasses are social or gregarious plants, which often cover large areas to the almost entire exclusion of other plants, and greatly exceed all other plant-families as regards number of individuals. They are adapted for existence in many kinds of habitat—running water (*Glyceria*, etc.), sand dunes (*Psamma*, *Elymus*, etc.), moors (*Nardus*, etc.). It is fairly easy to understand why Grasses are such dominant and aggressive plants. Their

seeds in most cases germinate quickly, and at a low temperature; the pointed shoot, enclosed by its sheath, can grow up to the air and light even when other plants are crowded in the spot where the Grass seed has fallen, while the numerous thread-like roots secure a hold even in the thinnest and poorest soil. Most Grasses are perennial, and their rhizomes either creep onwards or branch freely, but remain short; in the latter case the plant is tufted. The rhizome sends up erect shoots which bear foliage-leaves, and often end in an inflorescence. In most Grasses the "nodes" are more or less swollen, but as a rule this is due to thickening of the lower part of the leaf-sheath and not to thickening of the stem itself. The "nodes" consist largely of soft parenchyma whose cells are capable of growth, and when a shoot is laid in a horizontal position the "nodes" curve so as to bring the tip of the shoot into the erect position. The "ligule" present in most Grasses (see p. 263) may serve to prevent rain-water from entering the leaf-sheath, but this is doubtful. The flowers are carried well above the vegetative region of the plant; this is an obvious aid in wind-pollination.

Some of the commoner Grasses should be examined—*e.g.* Vernal Grass (*Anthoxanthum odoratum*, slender, glabrous, 1-2 ft. high, spike-like panicle about 2 in. long, two stamens), Timothy Grass (*Phleum pratense*, 1-3 ft. high, leaves with rough edges, spike cylindrical and 2-4 in. long), Meadow Foxtail (*Alopecurus pratensis*, like *Phleum*, but with sheaths of upper leaves loose, no palea in spikelet), Bent Grass (*Agrostis vulgaris*, panicle with branches in whorls, spreading out during flowering), Hair Grass (*Aira*, like Oat, but spikelets smaller and one- or two-flowered; *A. caespitosa* has flat, stiff leaves, with rough upper surface; *A. flexuosa*, a heath grass, has narrow, rolled-up leaves), Oat (*Avena*, loose panicle of several-flowered spikelets; outer empty glumes lanceolate, flowering ones smaller and 2-lobed, with a long, bent awn), Soft Grass (*Holcus lanatus*, 1-2 ft., with downy hairs on stem and leaves, giving plant a pale and soft appearance), Mat Grass (*Nardus stricta*, a tufted, wiry heath-grass, with fine bristle-like leaves, rolled up; spikelets small in two rows, on one side of spike), Couch

Grass (*Triticum repens*, with long creeping rhizome, spike 3-5 in. long, with spikelets on two opposite sides; Wheat belongs to same genus, but is annual), Rye Grass (*Lolium perenne*, 1-2 ft. high, leaves all near base, spike 6-12 in. long, spikelets spaced out in two opposite rows), Bromes (*Bromus*, spikelets large in a loose panicle, flowering glumes with long awns; *B. sterilis* and *B. mollis* are very common), Fescue (*Festuca*, panicle compact, with numerous spikelets. Sheep's Fescue has leaves mostly "radical" and rolled up, flowering glume with short awn; Meadow Fescue has flat leaves, no awn), Cock's-foot (*Dactylis*, a coarse, stiff plant, leaves rough at edges, spikelets in dense clusters on the branches of a spreading panicle), Dog's-tail (*Cynosurus*, leaves short, narrow, and mostly "radical"; stem wiry, 1-2 ft. long; spike, 1-3 in. long, semi-cylindrical, with clusters of spikelets all turned to one side), Quake Grass (*Briza media*, spikelets ovate at ends of branches of loose spreading panicle), Meadow Grass (*Poa*; commonest species *P. annua*, about 6 in. high, with flat leaves; panicle loose and spreading, about 2 in. long; spikelets all stalked; flowers all year round, and often passes through its life-cycle in a few weeks). Rushes and Sedges resemble Grasses to some extent in habit and mode of life. (See characters of Juncaceae and Cyperaceae in Appendix III.)

395. The Arborescent Type. We have already studied the characters of **shrubs** and **trees** (Ch. V. and Ch. IX., especially pp. 193–209, 368–84). There is, of course, no sharp distinction between shrubs and trees; various plants which form large trees when growing in sheltered or low-lying places are reduced to stunted shrubs when they occur on high mountains or wind-swept ridges. On Dartmoor, for instance, there are several patches of gnarled and stunted oak trees, doubtless of great age, growing among granite boulders along river-valleys, at a height of about 1,500 ft. On several "tors" (granite-caps on hills) there grow Rowan (Mountain Ash) plants reduced to low-creeping shrubs a few inches high; in one case the flat top of a tor, about 1,800 feet above sea-level, was covered with this dwarf Rowan.

Some further points relating to the biology of trees (pp. 373–4) may be mentioned here. One often sees on high exposed places inland, as well as near the coast, trees which have grown obliquely, sometimes almost horizontally, after reaching a certain height; in other cases the trees growing in such situations are erect, but growth has occurred almost entirely on one side. If you see examples of such trees, try to discover the causes of their bent or one-sided growth. Note the direction of the bend or that of the well-grown side of the tree, then find out the directions and characters (whether dry or moist, cold or warm) of the prevailing winds. At what time of year will the prevailing wind have most influence on the tree's growth, and in what way?

The process of secondary growth in thickness (see pp. 193–7) is obviously correlated with the continual increase of leaf-area on one hand and of root-area on the other. Each bud which unfolds in spring produces a branch which bears buds; next year, each of the latter may produce a branch, and so on. Meanwhile, the root-system is also branching, each branch producing fresh crops of root-hairs. The increasing rates of transpiration and root-absorption are met by the provision of additional water-conducting tubes (vessels); while the increasing amount of organic food produced by photosynthesis is conducted by the additional sieve-tubes to buds, cambium, growing-points of root-branches, and to medullary rays. All these tissues are growing in extent year by year, their growth being intimately correlated. That the increasing weight of the foliage borne by the branches of trees is practically counterbalanced by the increasing amount of wood formed each year is shown by the fact that the vertical distance between the summer-position of a branch, when it is bent down by the weight of the leaves, and the winter-position, when it has risen owing to the loss of the leaves, remains practically the same year after year.

396. Conclusion. The student who has worked through the course of instruction outlined in this book, and has followed up the suggestions thrown out with regard to personal observations and experiments, should have gained

a fairly sound and well-balanced knowledge of the Biology of Plants. There are many points concerning which our knowledge is incomplete, and many problems which await solution. This is especially the case with regard to plant-adaptations, about which one is often too prone to generalise from limited observations. The external and internal factors which control the morphology and physiology of plants are not always obvious or easy to unravel.

APPENDIX I.

GREEK AND LATIN ROOTS OF BOTANICAL TERMS.

The origin of most of the scientific terms used in this book can be traced by means of the appended lists of Latin and Greek roots, and a knowledge of them will enable the student to more clearly comprehend the precise meaning of the terms derived from them. In many cases, however, a derived word has acquired a widely different meaning from that which it should have according to its strict derivation.

GREEK.

a-, *without* (apetalous); **acro-**, *summit* (acropetal); **actino-**, *rayed* (actinomorphic); **adelphos**, *brother* (monadelphous); **amphi-**, *both* (amphibious); **ana-**, *up* (anabolism); **andr-**, *of man* or *male* (androecium); **anemos**, *wind* (anemophily); **angios**, *a vessel* (angiosperm); **apo-**, *away from* (apocarpous); **bio-**, *life* (biology); **bolos**, *a throwing*; **carp**, *fruit* (epicarp); **cata**, *down* (catabolism); **chlamys**, *a cloak* (archichlamydeae); **chloro-**, *green* (chlorophyll); **chromo-**, *colour* (chromoplast); **cleisto-**, *closed* (cleistogamous); **derma**, *skin* (epidermis); **di-**, *twice* (dicotyledon); **dich-**, *apart* (dichotomous); **dynamis**, *strength* (tetradynamous); **endo-**, *within* (endocarp); **epi-**, *on* (epidermis); **ergon-**, *work* (energy) **gamos**, *marriage* (polygamy); **gē**, *earth* (geotropism); **-gen**, *producing* (endogenous, oxygen); **gyn-**, *of woman* or *female* (gynaecium); **helios**, *sun* (heliotropism); **heteros**, *different* (heterogenous); **histos**, *web*, *tissue* (histology); **homos**, *same* (homology); **hypo-**, *under* (hypodermis); **logos**, *science* (physiology); **mega-**, *large* (megaspore); **meros**, *part* (mericarp); **meso-**, *middle* (mesocarp); **micro-**, *little* (microspore); **mono-**, *single* (monadelphous); **morphe**, *form* (morphology); **-oecium** (**oikos**), *house* (androecium); **-oid**, *like* (bacteroid); **orthos**, *straight* (orthostichies); **peri-**, *around* (pericycle); **-phile**, *loving* (thermophile); **phobe**, *hating* (photophobic); **phyll**, *leaf* (mesophyll); **phyte**, *plant* (spermaphyta); **plasma**, *anything formed* (protoplasm); **pod**, *foot* (monopodial); **poly**, *many* (polypetalous); **protos**, *first* (protoplasm); **pseudo**, *false* (pseudocarp); **sapros**, *putrid* (saprophyte); **schizo-**, *split* (schizocarp); **scleros**, *hard* (sclerenchyma); **sperma**, *seed* (endosperm); **syn-**, *together with* (syncarpous); **tetra**, *four* (tetradynamous); **thēe**, *a case* (theca); **tropos**, *direction* (heliotropism); **xero-**, *dry* (xerophilous); **zygon**, *a yoke* (zygomorphic); **xylon**, *wood* (xylem).

LATIN.

ad, *to* (adhesion); **albus,** *white* (alburnum); **amplexus,** *embraced* (amplexicaul); **apiculus,** *little apex* (apiculate); **arena,** *sand* (arenaceous); **argilla,** *clay* (argillaceous); **auriculus,** *little ear* (auriculate); **axilla,** *armpit* (axil, axillary); **bacillum,** *little staff* (bacillus); **bi-,** *twice* (bifid, bipinnate); **bulbus,** *onion* (bulb); **caducus,** *fallen* (caducous); **capillus,** *hair* (capillary); **capitulum,** *little head*; **capsula,** *little box* (capsule); **carcer,** *prison* (carcerulus); **carn-,** *flesh* (carnivorous); **caruncula,** *small piece of flesh* (caruncle); **caulis,** *stem* (caulicle); **coagulum,** *rennet* (coagulation); **com- (cum),** *with* (compound, collateral); **corona,** *crown*; **corolla,** *little crown*; **corymbus,** *bunch of flowers* (corymb); **cutis,** *skin* (cuticle); **decurro,** *to run down* (decurrent); **decusso,** *to divide crosswise* (decussate); **dehisco,** *to open* (dehiscent); **duramen,** *hardness*; **equito,** *to ride on horseback* (equitant); **ex,** *without* (exalbuminous); **-fid,** *cleft* (pinnatifid); **fistula,** *pipe* (fistular); **flaccidus,** *withered* (flaccid); **flos,** *flower* (floral); **folia,** *leaf* (foliage); **folliculus,** *little bag* (follicle); **fugo,** *to flee* (fugaceous); **gibbus,** *hump* (gibbous); **glaber,** *smooth* (glabrous); **glaucus,** *bluish grey* (glaucous); **hasta,** *spear* (hastate); **haustus,** *drawing up water* (haustorium); **hispidus,** *bristly* (hispid); **humus,** *soil* (humus); **imbrex, -icis,** *a roof tile* (imbricate); **impar,** *unequal* (imparipinnate); **inter,** *between* (intercellular); **involucrum,** *cover* (involucre); **labium,** *lip* (labiate); **lignum,** *wood* (lignified); **ligula,** *strap* (ligulate); **loculus,** *little place* (trilocular); **nectar,** *honey*; **nodus,** *knot* (node); **nuto,** *to nod* (nutation); **nux,** *nut* (nucellus); **ovum,** *egg* (ovule); **papilio,** *butterfly* (papilionaceous); **par,** *equal* (paripinnate); **paries,** *wall* (parietal); **pelta,** *shield* (peltate); **persona,** *mask* (personate); **peto,** *to seek* (acropetal); **pinna,** *wing* (pinnate); **pluma,** *feather* (plumule); **pulvinus** *cushion*; **pyxis,** *box* (pyxidium); **racemus,** *bunch of grapes* (raceme); **radix,** *root* (radicle); **renes,** *kidney* (reniform); **rota,** *wheel* (rotate); **sagitta,** *arrow* (sagittate); **sectus,** *cut* (pinnatisect); **serra,** *saw* (serrate); **siliqua,** *pod* or *shell*; **subula,** *awl* (subulate); **umbella,** *parasol* (umbel); **urceolus,** *little pitcher* (urceolate); **vas,** *vessel* (vascular); **versatilis,** *revolving* (versatile); **verticillus,** *whirl of a spindle* (verticillate).

The following terms are used in Floras to indicate the species of plants. These plant-names are usually descriptive of some peculiarity of form or habit, and are therefore helpful in remembering the plants, once their meanings are known:

Acaulis, *stemless*; **acer, acris,** *sharp*; **aculeatus,** *prickly*; **aestivalis,** *of summer*; **affinis,** *neighbouring*; **agrestis,** *of cultivated fields*; **albus,** *white*; **amarus,** *bitter*; **angustus,** *narrow*; **aquatilis, aquaticus,** *of water*; **arenarius,** *of sand*; **arvensis,** *of fields*; **asper,** *rough*; **caeruleus,** *blue*; **caesius,** *bluish grey*; **caespitosus,** *matted*; **campester, -tris,** *in fields*; **candidus,** *white and shiny*; **cernuus,** *podding*; **cinereus,** *ashy*; **claviculatus,** *having hooks or tendrils*; **coccineus,**

scarlet; **collinus**, *on low hills*; **columbinus**, *dove-coloured*; **communis**, *growing in society*; **comosus**, *tufted*; **crispus**, *curled*; **cruciatus**, *cross-like*; **demersus**, *under water*; **dissectus**, *deeply divided*; **distichus**, *in two rows*; **dubius**, *doubtful*; **effusus**, *expanded*; **elatus**, *tall*; **fistulosus**, *tubular*; **flavus**, *golden yellow*; **flexuosus**, *zig-zag*; **-florus**, *-flowered*; **fluitans**, *floating*; **fluvialis**, *in streams*; **foetidus**, *stinking*; **-folius**, *-leaved*; **fruticosus**, *shrubby*; **fuscus**, *brown*; **glomeratus**, *clustered*; **gracilis**, *slender*; **gramineus**, *grass-like*; **graveolens**, *scented*; **hederaceus**, *ivy-leaved*; **hirtus**, *hairy*; **hyemalis**, *in winter*; **incarnatus**, *flesh-coloured*; **junceus**, *rush-like*; **laevis**, *smooth*; **latus**, *broad*; **littoralis**, *of the shore*; **lucens**, *shining*; **luteus**, *rich yellow*; **maculatus**, *spotted*; **marinus**, **maritimus**, *of the sea*; **mollis**, *soft*; **muralis**, *on walls*; **nanus**, *dwarf*; **natans**, *floating*; **nemorosus**, *of woods*; **niger**, *black*; **nitens**, *shining*; **nodosus**, *knotted*; **nutans**, *nodding*; **officinalis**, *of the drug-shop*; **oleraceus**, *eatable*; **pallens**, **pallidus**, *pale*; **palustris**, *of a marsh*; **patens**, *spreading*; **pilosus**, *hairy*; **pratensis**, *of a meadow*; **procumbens**, *bending forwards*; **pulcher**, *pretty*; **radicans**, *rooting*; **ramosus**, *branched*; **repens**, **reptans**, *creeping*; **riparius**, *by river-sides*; **ruber**, *red*; **salinus**, *of salt marshes*; **sanguineus**, *blood-red*; **sativus**, *sown or planted*; **saxatilis**, *of rocks*; **scutellatus**, *like a plate or shield*; **segetus**, *of corn-fields*; **sempervirens**, *evergreen*; **speciosus**, *handsome*; **squarrosus**, *spreading*; **stellatus**, *star-like*; **strictus**, *upright*; **succisus**, *abruptly cut off*; **sylvestris**, **sylvaticus**, *of woods*; **tectorum**, *on roofs*; **tenellus**, *delicate*; **tinctorius**, *used in dyeing*; **tremulus**, *quivering*; **trivialis**, *by the road-side*; **uliginosus**, *in swamps*; **urbanus**, *of the town*; **urens**, *stinging*; **vaginatus**, *sheathed*; **veris**, **vernus**, *in spring*; **vescus**, *feeble*; **viridis**, **virens**, *green*; **vulgaris**, *common*.

APPENDIX II.

DEFINITIONS OF BOTANICAL TERMS.

Absciss layer, a layer of cork-cells formed across the base of a leaf (or other organ) which is cut off from the plant by the splitting of the absciss-layer. **Absorption,** the taking-in of liquids and gases. **Achene,** a dry one-seeded indehiscent fruit. **Acicular,** needle-shaped, *e.g.* Pine leaf. **Acropetal,** the order in which parts—*e.g.* rootlets, branches, leaves, flowers—are formed when the youngest is nearest the growing apex of the axis. **Actinomorphic** flowers, etc., have radial symmetry, *i.e.* they can be divided into similar halves by two or more planes. **Acuminate,** taper-pointed, drawn out into a long point. **Adhesion,** union between unlike parts of a flower, *e.g.* in epipetalous stamens. **Adventitious,** developed outside of the normal order, or on unusual parts of the plant; applied to roots and buds. **Aerobic,** requiring free oxygen for life or for active growth. **Aestivation,** the arrangement (folding, etc.) of the parts of a flower in the bud; also called Praefloration. **Aggregate fruit,** one formed from a flower with several free carpels. **Alae,** the wings or side-petals of a Papilionaceous flower. **Alate,** winged, *e.g.* stems of Thistles. **Albumen,** (*a*) the proteid forming the white of an egg; (*b*) the old name for endosperm. **Albuminous** = endospermic. **Alburnum,** the sapwood or soft and light-coloured outer portion of the wood in a Dicotyledonous tree. **Alternate,** (*a*) leaves arranged singly on the stem, one after another; (*b*) petals alternate with sepals, or stamens with petals, when they stand over the spaces between them. **Amentum** = catkin. **Amides,** nitrogenous substances forming an intermediate stage in the elaboration of proteids from sugar. **Amplexicaul,** applied to a leaf which clasps the stem with its base. **Anabolic processes,** those which lead to the building-up of complex organic substances from simpler ones. **Anaerobic,** able to grow in the absence of a supply of oxygen, or even unable to live and grow in its presence. **Andrecium,** the collective name given to the stamens present in a single flower. **Anemophilous,** wind-pollinated. **Angiosperms,** plants in which the ovules are developed in a closed chamber (ovary). **Annuals,** plants which germinate, flower, set seeds, and die in one season. **Anther,** the essential part of a stamen, in which the pollen-grains are formed. **Apetalous,** without petals. **Apiculate** leaf, one having a small hard point at its tip. **Apocarpous pistil,** one consisting of a single

carpel or of several carpels which are quite free from each other. **Argillaceous** = clayey, applied to soils containing a large proportion of clay. **Aril,** an outgrowth on a seed, usually arising from the stalk or from the micropyle; usually a fleshy cup (Yew, Nutmeg, Spindle-tree), a spongy mass (Castor-oil, Water-lily), or a tuft of hairs (Willow, Poplar, Willow-herb). **Aristate,** bearded or awned, applied to the bracts of certain grasses, *e.g.* Barley. **Assimilation,** the taking-in of raw food-materials and their elaboration into the plant's own living substance; usually limited to carbon-assimilation (photosynthesis). **Auriculate** leaf, one having auricles, or ear-like appendages, at the base of the blade. **Awn,** or "beard," a long, bristle-like appendage on the bracts of some grasses. **Axil,** the angle between the stem and the upper surface of a leaf-base. **Axile placentation,** that in which the ovules are attached to a central axis in the ovary, where the ventral edges of the carpels meet each other. **Axillary,** arising in the axil of a leaf. **Axis,** the main trunk of a root or shoot, as distinguished from the appendages it bears.

Bacillus, a rod-shaped Bacterium, occurring singly or more often united into chains. **Bacteria,** minute plants, without chlorophyll; rod-shaped, spherical, or spiral; occur abundantly in air or soil; mostly aerobic, but some anaerobic. **Bark,** the dead tissue lying on the outer side of a cork-producing layer in a stem or root. **Bast** or **Phloëm,** the kind of vascular tissue which consists chiefly of sieve-tubes, serving to conduct elaborated nitrogenous food-material in the plant. **Berry,** a fruit whose wall (pericarp) is fleshy and does not include any hard portion ("stone"). **Biennials,** plants whose life-history extends through two successive years—the first being devoted to the making and storage of food, the second to the production of flowers and seeds. **Bipinnate** leaf, one in which the pinnae or leaflets are themselves again pinnate, *e.g.* Sensitive Plant. **Bract,** a leaf in whose axil a flower or a flowering-shoot arises. **Bud,** a young shoot, consisting of a short axis with young leaves covering its growing-point. **Bulb,** an underground shoot, consisting of a short disc-like stem bearing roots, buds, and swollen leaves (or leaf-bases) packed with food-materials (starch, sugar, inulin). **Bulbil,** small bulbs produced as buds in axils of foliage leaves, or replacing flowers; they contain food, and on falling to the ground produce new plants.

Caducous, falling off early, applied to sepals and petals of flowers. **Callus,** (*a*) new tissue formed by active growth of cambium on exposed surfaces, *e.g.* in cuttings and where branches have broken off a tree; (*b*) a modified form of cellulose which blocks up the pores of sieve-tubes in winter. **Calyx,** the outer series of parts (sepals) in a "typical" flower. **Cambium,** the layer of living cells whose active growth and division cause secondary thickening of stems and roots. **Capillarity,** the force which causes a liquid to move over the surface of a solid with which it is in contact, and which makes water, etc., rise in fine tubes and in the spaces between soil-particles. **Capitulum,** or flower-head, a form of racemose in-

florescence in which the flowers are sessile and crowded on the end of the flowering shoot. **Capsule,** a fruit which opens when ripe in order to let the seeds escape. **Carbohydrate,** a substance consisting of carbon, hydrogen, and oxygen, the two latter elements being present in the same proportion as in water. **Carcerulus,** a fruit which splits into several hard dry one-seeded parts; occurs in Labiatae, Boraginaceae, and Malvaceae. **Carina** = keel. **Carnivorous** = **Insectivorous.** **Carpel,** one of the innermost series of parts in a "typical" flower; a leaf on which are usually developed the *ovules.* **Caruncle,** applied to an aril when it forms a mass of tissue on the seed, *e.g.* Castor-oil. **Caryopsis,** applied to the fruit of grasses, which differs from an ordinary achene in having pericarp and testa fused. **Catabolic** processes, those by which complex substances break down into simpler ones, energy being set free. **Catkin,** a form of racemose inflorescence in which the flowers are unisexual. **Caulicle,** a little stem; often applied to the axis of the Dicotyledonous embryo. **Cell,** the unit of plant-tissues, consisting essentially of a mass of protoplasm which contains a nucleus and is covered by a cell-wall. **Cell-sap,** the liquid contained in a cell; it contains salts, sugars, organic acids, etc. **Cell-wall,** the envelope of an ordinary cell; it consists originally of cellulose, but later often becomes altered more or less completely into woody, corky, gummy, and other substances, and thickened in various ways. **Cellulose,** the substance of which most cell-walls consist, at any rate when young; it is a carbohydrate, with the same percentage composition as starch and inulin. **Centrifugal,** applied to an inflorescence whose terminal or central flowers open first. **Centripetal,** flowering from base or circumference towards apex or centre. **Chlorophyll,** the green colouring-matter of ordinary plants, contained in chloroplasts; absorbs light-rays which supply the energy required for photosynthesis; is only formed in presence of light and of iron. **Chloroplasts** *or* **Chlorophyll-grains,** masses of protoplasm containing chlorophyll, found only in the cells of organs exposed to the light. **Chromoplasts,** masses of protoplasm (plastids) which contain pigments other than chlorophyll; yellow and most red flowers owe their colours to chromoplasts. **Cilia,** fine whip-like protoplasmic threads, by which certain cells (*e.g.* Bacteria, simple Algae, reproductive cells of various lower plants) are enabled to swim in water. **Cladode,** a branch which assumes the functions, and sometimes the shape, of a foliage-leaf. **Claw,** the narrow lower part of the petal in Crucifers and some Caryophyllaceae, the upper part (limb) being broad and spreading. **Clay,** soil consisting of minute particles, which when damp is sticky and impervious to water; consists of hydrated silicate of alumina. **Cleistogamic** flowers do not open, have minute petals, and are self-pollinated. **Coagulation,** a clotting, the conversion of a fluid into a solid or jelly. **Coccus,** the dry one-seeded carpels or nutlets, into which the fruit of Geraniaceae, etc., split. **Cohesion,** union between *like* parts of a flower—*i.e.* between sepal and sepal, petal and petal, etc. **Collateral bundle,**

one consisting of bast on the outer side and wood on the inner. **Collenchyma,** strengthening or supporting tissue (found below *epidermis of leaf-stalks, herbaceous stems, flower-stalks, etc.*), consisting of cells not much longer than broad, which contain living protoplasm and have cellulose walls, strongly thickened at the corners. **Column,** the prolongation of the flower-axis in Orchids, on which the stigma and the stamen are carried up. **Combustion,** the chemical union of any substance with oxygen, heat being produced. **Compost,** a rich potting-soil, formed by mixing ordinary soil or sand with leaf-mould, road-scraping, well-rotted farmyard manure, etc. **Compound,** (*a*) a substance consisting of two or more elements chemically united; (*b*) applied to a leaf whose lamina is divided into several distinct pieces (leaflets). **Connate,** when two similar parts are slightly connected. **Connective,** the tissue at the back of an anther, forming a continuation of the stalk (filament) and containing a vascular bundle. **Contorted** or **Twisted,** applied to aestivation when one edge of each petal is covered and the other exposed. **Convolute,** applied to vernation and aestivation when one part is rolled up longitudinally within another. **Cordate,** heart-shaped, with two rounded lobes at the base; applied to leaves. **Cork,** a tissue formed on old stems and roots (also on wounded surfaces and in other places), consisting of dead cells whose walls have been chemically altered so as to become impermeable to water and gases. **Cork-cambium,** a layer of actively growing and dividing cells by which cork is produced. **Corm,** an underground shoot consisting of a swollen stem (containing stored food), which bears thin membranous scales, buds, and roots. **Corolla,** the inner series of perianth-leaves (petals) in a "typical" flower; usually coloured, for the attraction of insects. **Corona,** a ring-like outgrowth from the perianth-tube or corolla-tube, which increases the conspicuousness of the flower or protects the inner parts from rain or from unwelcome insects. **Corymb,** a form of raceme in which the lower flowers have longer stalks, bringing them to a level with the upper flowers and forming a flat-topped inflorescence. **Cosmopolitan,** distributed very widely over the world. **Costate,** ribbed or veined. **Cotyledons,** the earliest leaves of the young plant (embryo), formed inside the seed; usually simpler in form than the later leaves. **Cremocarp,** a fruit which splits into two one-seeded parts; characteristic fruit of Umbellifers. **Crenate,** applied to leaves when the margin has rounded teeth. **Cruciform,** four parts, *e.g.* petals, arranged so as to form a cross; applied to corolla of Crucifers. **Cuticle,** the outer part of the walls of epidermis-cells, chemically altered so as to be nearly impermeable to water and gases; found on leaves, young stems, etc. **Cutting,** part of a plant separated from the parent; on being placed in the soil it forms roots and produces a new plant. **Cyme,** a branch-system in which the main axis ceases to grow, while one or more of its branches grow on and then repeat the behaviour of the original axis. **Cytase,** the ferment (enzyme) which converts cellulose into sugar.

Decay, *the decomposition of organic substances, set up by Bacteria*, yeasts, moulds, etc. **Deciduous**, falling off at the end of the first season of growth; applied to leaves. **Decomposition**, the splitting up of a chemical compound into simpler compounds or into elements. **Decurrent**, applied to a leaf whose blade is prolonged down the stem below the point of attachment. **Decussate**, the arrangement of leaves in crossed pairs, forming four rows on the stem. **Dehiscence**, the opening of anthers and of fruits. **Dentate**, applied to a leaf whose margin bears short triangular teeth. **Diadelphous**, applied to Papilionaceae when there are nine stamens united into a bundle, and one free. **Diastase**, the ferment (enzyme) which converts starch into sugar. **Dichasium**, the form of cyme in which two daughter-axes are given off by the main axis each time its growth comes to a close; the typical inflorescence of Caryophyllaceae. **Dichlamydeous**, applied to flowers when the perianth consists of two distinct series of parts (sepals and petals). **Dichotomy** or **Forking**, a form of branching, rarely found in higher plants, in which the main axis divides or forks into two daughter-axes. **Diclinous**, unisexual, *i.e.* having the stamens and pistil in separate flowers. **Didynamous**, applied to the andrecium when it consists of two pairs of stamens of unequal lengths, *i.e.* two long and two short stamens. **Digitate**, applied to a compound leaf when the leaflets all arise from the top of the stalk—*e.g.* Lupin, Horse-chestnut. **Dioecious** or **Dioicous**, having the staminate and pistillate flowers on separate plants. **Disc**, an outgrowth from the receptacle of a flower, usually secreting honey. **Disc-floret**, applied to the inner florets of a capitulum when they differ in form from the outer florets (ray-florets). **Dissected**, deeply divided into many narrow lobes or leaflets. **Dissepiments**, the partitions of an ovary or fruit. **Distichous**, arranged in two opposite rows—*e.g.* leaves of Grasses, Broad Bean, etc. **Drupe**, a fruit whose wall consists of skin (epicarp), flesh (mesocarp), and stone (endocarp); indehiscent and usually one-seeded. **Duramen** or **Heart-wood**, the harder and darker inner portion of the wood in a Dicotyledonous tree.

Ebracteate, without bracts. **Egg-cell** or **Ovum**, the female cell in the embryo-sac; when fertilised by a male cell from the pollen-tube it develops into the embryo. **Elliptic**, applied to a leaf which is oval, but more or less pointed at each end. **Emarginate**, applied to a leaf which is slightly notched at the top. **Embryo**, the young plant in the seed, developed from the egg-cell of the ovule. **Embryo-sac**, the tissue formed by growth of the megaspore (embryo-sac mother-cell) embedded in the nucellus of an ovule. **Emergences**, structures which grow from the epidermis (sometimes from underlying tissues in addition) and which do not come under the heading of leaves or branches or roots. **Endemic**, confined to one district or country. **Endocarp**, the innermost layer of the fruit-wall (pericarp), when the latter is divided into distinct layers. **Endodermis**, the innermost layer of the cortex; its cells may contain starch, or may (especially in roots) have corky walls (which perhaps prevent air

from entering the wood-vessels). **Endogenous,** arising from internal tissues. **Endosperm,** the nutritive tissue formed by the growth and division of the central cell of the embryo-sac; if it persists in the ripe seed, the latter is called *endospermic*; if it is all absorbed by the embryo, the seed is *non-endospermic*. **Ensiform,** sword-shaped, applied to leaves of Iris, Gladiolus, etc. **Entire,** applied to leaves, sepals, petals, when they are not toothed, lobed, or divided at the edge. **Entomophilous** = insect-pollinated. **Environment,** the surroundings in which a plant lives (including the various stimuli it receives from outside, when used in a wide sense). **Enzymes** or **Ferments,** soluble nitrogenous substances (secreted by living protoplasm of plants and animals) which convert complex organic substances into simpler ones, without undergoing any apparent change themselves; enzymes of various kinds are secreted by germinating seeds, tubers, bulbs, corms, etc., by leaves, pollen-tubes, parasitic organs, Bacteria, Yeasts, Moulds, and other Fungi. **Ephemerals,** plants which can germinate, flower, and set seed several times in succession during a single year. **Epicalyx,** a ring of bract-like leaves found outside of the calyx in some flowers (*e.g.* Potentilla, Strawberry, Mallow). **Epicarp,** the outermost layer of the fruit-wall (pericarp), forming the "skin" of a drupe or berry. **Epicotyl,** the part of the axis of a young plant lying above the cotyledons and ending in the plumule. **Epidermis,** the "skin-layer" which covers the surface of the entire plant; on the shoot it is usually covered with cuticle, and in green parts usually bears stomata; on the root it is without cuticle, bears absorbing hairs, and is thickened at the root-tip to form the root-cap. **Epigynous** flower, one in which the receptacle has grown up around, and closed above, the ovary, so that the other parts of the flower arise above the ovary, and the latter is said to be inferior. **Epipetalous,** applied to stamens when they are inserted on the petals or corolla. **Epiphyllous,** applied to stamens when they are inserted on the parts of a perianth. **Epiphyte,** a plant which grows upon, but takes no food from, another plant. **Equitant,** riding, applied to leaves which overlap each other longitudinally, and are V-shaped in cross-section, *e.g.* Iris. **Etaerio,** a collection of carpels forming an aggregate fruit, *e.g.* Buttercup, Columbine, Blackberry. **Etiolation,** the effects of darkness on a plant which normally grows in light; an etiolated plant has small leaves, no chlorophyll, and weak stems with long spaces ("internodes") between the leaves. **Exalbuminous** = non-endospermic; see **Endosperm.** **Exogenous,** arising from tissue at or near the surface. **Exserted,** projecting beyond, *e.g.* stamens hanging out from the mouth of the corolla. **Exstipulate,** without stipules. **Extrorse,** applied to anthers which shed the pollen outwards, *i.e.* away from the pistil.

Fats, compounds consisting of carbon, hydrogen, and oxygen; each capable of separation into glycerin and an organic acid; occur in many seeds, also in the winter-food stored in the medullary rays of certain trees. **Fermentation,** a chemical change set up in an

organic substance by Bacteria, except alcoholic fermentation of sugar which is caused by Yeast. **Fertilisation**, the fusion of male cell from pollen-tube with female cell (egg-cell) in ovule, resulting in the formation of an embryo. **Fibre**, a long, narrow cell with tapering ends, thick woody wall, no living contents; found in wood and in hard-tissue (sclerenchyma). **Fistular**, applied to the hollow stems and petioles of Umbellifers, Broad Bean, etc. **Flaccid**, shrunken or flabby, applied to (1) leaves drooping for want of water, (2) cells contracted by loss of cell-sap. **Flower**, a short axis bearing one or more stamens or carpels, with or without an envelope (perianth). **Follicle**, a fruit formed from a single carpel, containing several seeds and opening along the seed-bearing side (ventral suture). **Free central placentation**, that in which the ovules are developed on an axis which grows up from the bottom of the ovary and is not connected with the outer wall. **Fruit**, the product of the growth induced by fertilisation in the persistent parts of a flower; includes the ripened ovary with its seeds, often with other parts, *e.g.* receptacle. **Fugacious**, fleeting; applied to parts of a flower which fall off early, *e.g.* sepals of Poppy. **Fungi**, flowerless lower plants which contain no chlorophyll, and are therefore obliged to live as saprophytes or parasites; the vegetative body consists of branching threads, called "hyphae."

Gamopetalous (**Sympetalous**) flower, one in which the petals are united. **Gamosepalous**, sepals united. **Geotropism**, the response made by the various organs of a plant to the stimulus of gravity. **Germination**, the awakening of the dormant embryo in a seed to active life and growth. **Gibbous**, swollen or pouched on one side, *e.g.* corolla of Valerian. **Glabrous**, smooth, applied to organs without hairs on the surface. **Gland**, a cellular secreting organ. **Glaucous**, bluish green. **Glumes**, the scales enclosing the spikelet of flowers in Grasses. **Grafting**, the process of inserting into the stem of one plant a cutting, with buds on it, of another plant. The cutting is called the "graft"; the stem into which it is placed is the "stock." **Ground-tissue**, the tissue lying within the epidermis and outside of the vascular bundles. **Guard-cells**, two curved cells surrounding the opening of a stomate, and capable of changing in shape so as to open or close the stomate. **Gymnosperms**, plants in which the ovules are freely exposed, not being developed in an ovary as in Angiosperms. **Gynandrous**, stamens and style united to a column, as in Orchids. **Gynecium** = **Pistil**.

Habit, the general appearance of a plant or its mode of growth—*e.g.* bushy, tufted, creeping, climbing, parasitic. **Habitat**, the surroundings in which a plant is growing—*e.g.* marshes, ponds, heaths, shores. **Hardy** and **Half-hardy**, relative terms to denote the ability or otherwise of a plant to endure the winter cold in the district where it grows. Several garden plants are hardy in South Devon, but not in Scotland, for example. **Hastate**, applied to a leaf with two lobes at the base of the blade which point outward. **Haustorium**, a "sucker" which a parasitic plant sends into its host in order to

obtain its food. **Head,** a terminal collection of closely packed flowers, whether racemose or cymose; often used as equivalent to capitulum. **Heavy soil,** a clayey soil which is difficult to work with spade or plough. **Herbaceous** plants, or parts of plants, are not woody or persistent after the first year of growth. **Hermaphrodite,** applied to flowers having both stamens and pistil. **Hilum,** the scar on a seed, where it became detached from the seed-stalk. **Hispid,** covered with rough hairs. **Hoary,** covered with short hairs, giving the surface a mealy, frosted, or downy appearance. **Humus,** soil consisting largely of decaying organic matter—*e.g.* leaf-mould, peat. **Hybrid,** a "cross" resulting from the fertilisation of the ovules of one species by the pollen of another species. **Hydrophytes,** plants which grow in water, partly or entirely submerged. **Hygrophytes,** plants which grow in moist soil or on the sides of streams, ponds, etc. **Hyphae,** the branched threads which make up the *mycelium* or vegetative body of a Fungus. **Hypocotyl,** the part of the axis of a young plant which extends from the cotyledons to the radicle. **Hypogynous** flower, one in which the parts are attached successively on the knob-like or elongated receptacle. **Hypocrateriform** = salver-shaped, applied to a corolla with a long tube and a flat spreading limb, *e.g.* Primrose.

Imbricate, overlapping one another, applied to leaves, sepals, petals, chiefly in buds. **Imparipinnate,** pinnate with an odd terminal leaflet. **Imperfect,** applied to flowers which have some parts present but not fully developed, *e.g.* Holly. **Included,** not extending beyond the surrounding parts; applied to stamens which do not project beyond the mouth of the corolla. **Incomplete,** applied to flowers in which there is no perianth. **Indefinite,** many, but of uncertain number; applied to stamens when exceeding about 20, also applied to racemose branching. **Indehiscent,** applied to fruits which do not burst open to set the seeds free. **Indigenous,** native, belonging to the country. **Inferior,** applied to ovary when the receptacle has grown over it, so that the other parts of the flower arise above the ovary; also applied to calyx of a hypogynous flower. **Inflorescence,** the flower-bearing part of a shoot. **Internode,** the portion of a stem between two nodes (points where leaves arise). **Introrse,** applied to anthers which open inwards, towards the pistil. **Inulin,** a carbohydrate having the same percentage composition as starch and cellulose, but soluble in water. **Involucre,** a series of bracts arranged around the outside of an inflorescence or of a single terminal flower. **Irritability,** the property of responding to stimuli.

Kainit, a potash manure, consisting of potassium sulphate, potassium chloride, and magnesium chloride. **Keel,** the boat-shaped structure formed by the two anterior petals of a Papilionaceous flower.

Labellum, the largest of the three petals of an Orchid flower, often spurred at the base. **Labiate,** applied to a calyx or corolla which is divided into an upper and a lower lip. **Lamina,** the blade of a leaf or leaflet, typically flat and thin. **Lanceolate,** lance-shaped,

ground-tissue of plants, in which the cells are not much longer than broad. **Parietal placentation,** that in which the ovules are attached to the inner surface of the ovary-wall; found only in one-chambered (unilocular) ovaries. **Paripinnate,** pinnate with an even number of leaflets, without an odd end-leaflet. **Pedate,** palmate with three lobes, and the lateral lobes having similar lobes on their outer edge, *e.g.* Hellebore. **Pedicel,** the stalk which bears a single flower in an inflorescence. **Peduncle,** the axis which bears several pedicels or sessile flowers in an inflorescence. **Peloria,** applied to the regular flowers sometimes developed by plants which usually have zygomorphic flowers. **Peltate,** having the point of attachment on the face instead of at the edge. **Perennial,** of three or more years' duration. **Perfoliate,** when the leaf completely surrounds the stem so that the latter appears to pass through it. **Perianth,** applied to the envelope of the flower, especially when calyx and corolla cannot be distinguished. **Pericarp,** the wall of the fruit. **Pericycle,** the layer of tissue immediately outside the vascular cylinder of roots and leaves. **Perigynous** flower, one in which the receptacle is more or less cup-like, with the perianth and stamens inserted on the edge. **Perisperm,** reserve food formed from the nucellus of the ovule (compare Endosperm) outside of the embryo-sac. **Personate,** masked, applied to a gamopetalous two-lipped corolla, in which the lower lip is inflated and pressed against the upper so as to close the mouth of the corolla-tube. **Petal,** one of the parts or lobes of the corolla, typically brightly coloured. **Petaloid,** resembling petals in texture and colour. **Petiole,** the stalk of a leaf. **Phloem** = **Bast.** **Photosynthesis,** the process by which a green plant, with the aid of sunlight, makes organic food from carbon dioxide, water, and mineral salts. **Phyllode,** a petiole which has assumed the form and functions of a leaf-blade, the latter being undeveloped or falling off. **Pinnate,** applied to a compound or lobed leaf in which the leaflets or lobes are arranged in two opposite rows. **Pistil** or **Gynecium,** the carpel or carpels of a flower. **Pith,** the cellular tissue in the centre of Dicotyledonous stems. **Placenta,** the surface in an ovary on which the ovules are developed. **Plaited** or **Plicate,** folded like a closed fan, like many leaves before they unfold. **Plastids,** small grains of specialised protoplasm, which may be colourless (leucoplasts) or contain chlorophyll (chloroplasts) or other pigments (chromoplasts). **Plumule,** the terminal bud of the young plant, the shoot of the embryo. **Pod** = **Legume.** **Pollen-grains,** the cells formed in the pollen-sacs. **Pollen-sacs,** the chambers in the anther, containing the pollen-grains. **Pollen-tube,** a long tubular outgrowth formed in the germination of a pollen-grain; it contains the male cell, which fuses with the egg-cell and thus fertilises it. **Pollination,** the application of pollen to the stigma **Pollinia,** the coherent pollen-masses of Orchids, etc. **Polyadelphous,** having the stamens united by their filaments to form several bundles—*e.g.* Lime-tree; St. John's Wort. **Polycarpic,** fruiting several times in succession. **Polygamous,** having staminate, pistillate, and hermaphrodite flowers on the same

plant. **Polypetalous**, with free and separate petals. **Polysepalous**, with free and separate sepals. **Pome**, a fleshy fruit in which the fleshy part is formed from the receptacle. **Prickles**, hard appendages formed from the epidermis. **Protandrous** flower, one in which the stamens shed their pollen before the stigmas are in a condition or position for receiving pollen. **Proteids**, complex nitrogenous substances containing carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus; the sole nitrogenous food-substances for man, therefore of the utmost importance. **Protogynous** flower, one in which the stigmas are ready to receive pollen before the stamens have shed the pollen. **Protophloem**, the first-formed and therefore oldest part of the phloem (bast); it occupies the outer edge of the phloem in all roots and in most stems. **Protoplasm**, the living substance of plants, consisting essentially of proteids. **Protoxylem**, the first-formed part of the xylem (wood); it occupies the outer edge of the primary wood in the root, the inner edge in stems of Dicotyledons and most *Monocotyledons*. **Pruning**, *the removal of some of the* shoots (or roots) of a shrub or tree, to allow free access of light and air to the remaining shoots, to prevent the plant from growing long and weak, or to prevent growth of wood, etc., at the expense of fruit-production. **Pulvinus**, the swollen base found in many leaves, usually capable *of movements*. **Pyxidium**, *a capsule* which opens by the separation of a lid.

Raceme, an inflorescence having a main axis on which stalked flowers are developed in acropetal order. **Radicle**, the primary root developed at one end of the axis of the young plant. **Ray-florets**, the flowers developed at the margin of a head (capitulum), when they differ in structure from the central (disc-) florets. **Receptacle**, the dilated end of the flower-stalk, from which the parts of the flower arise. **Recurved**, bent moderately backwards. **Reflexed**, bent considerably backwards. **Reniform**, kidney-shaped, transversely oval but broadly cordate at the base. **Replum**, the partition which joins the two parietal placentas and divides the ovary into two chambers in crucifers. **Reticulate**, forming a network. **Reversion**, throwing-back, the appearance in a plant of characters not found in either of its parents but found in remote ancestors. **Rhizome**, or "root-stock," an underground shoot, usually growing horizontally and sending up leaves and flowers, or leafy and flowering shoots. **Ringent**, applied to a gamopetalous corolla with a widely open mouth. **Rosette**, a collection of leaves growing close together on, and radiating more or less horizontally from, a short stem. **Rotate**, applied to a gamopetalous corolla with a short tube and a spreading horizontal limb. **Runner**, a shoot creeping horizontally over the soil, usually with long internodes.

Sagittate, arrow-shaped, like the barbed head of an arrow, the lobes pointing backwards and not outwards as in **Hastate**. **Samara**, a winged dry indehiscent fruit. **Saprophyte**, a plant which obtains the whole, or part, of its food from dead organic substances. **Scape**, a "radical" flowering axis devoid of foliage-leaves. **Schizocarp**,

a fruit which splits into several one-seeded indehiscent parts. **Sclerenchyma**, *hard-tissue, consisting of fibres—i.e.* cells which have grown very long and narrow, and have the walls thick and woody; the cells are dead, and contain only water. **Sepals**, the parts or lobes of the calyx. **Septum**, a partition in an ovary or fruit. **Serrate**, toothed like a saw, applied to leaf-margin. **Sessile**, without a stalk. **Sieve-tubes**, rows of long cells found in the bast, the cross-walls separating the cells being pierced by canals through which the slimy proteid contents can travel from cell to cell along each sieve-tube. **Silicula**, a short and broad form of siliqua. **Siliqua**, the long *pod-like fruit of crucifers, which opens by the separation of two* valves, leaving the seeds on the two edges (placentas) of the replum. **Sinuate**, having several large blunt lobes on the smooth wavy margin—*e.g.* leaf of oak. **Spadix**, a fleshy spike, bearing sessile flowers, usually packed closely together. **Spathe**, a large bract enclosing a spadix. **Spathulate** or **Spatulate**, spoon-shaped, oblong with a long narrow base. **Spike**, an inflorescence with an axis bearing sessile flowers in acropetal order. **Spikelet**, the small groups of flowers in Grasses, enclosed by membranous bracts (glumes). **Spine**, (*a*) a stiff sharp woody outgrowth of a stem; (*b*) a sharp outgrowth on a leaf-margin. **Spur**, a tubular outgrowth of the base of a sepal, petal, or gamopetalous corolla. **Stamen**, one of the outer reproductive parts in a typical flower, consisting essentially of an anther with a long or short stalk (filament) continued up the back of the anther to form the connective. **Staminate** or "male" flower, one containing stamens, but no pistil. **Staminode**, a sterile or antherless stamen. **Standard**, the uppermost (posterior) petal in a Papilionaceous flower, outside of the others in the bud. **Starch**, a carbohydrate consisting of carbon, hydrogen, and oxygen; the commonest food-substance stored in plants, also the first visible product of photosynthesis in most green plants; found in grains, differing in shape and average size in different plants. **Stigma**, the more or less roughened (with small projections or hairs) receptive part of the style, to which pollen-grains adhere. **Stipitate** = stalked, applied to parts other than leaves. **Stipules**, leaf-like appendages at the base of a leaf, one on either side of its insertion on the stem. **Stolon**, a creeping stem growing along the surface; often used to include *Runners* and *Offsets*. **Stomate**, an opening in the epidermis of leaves, young stems, etc., surrounded by two curved cells (guard cells). **Strobilus**, a cone-like inflorescence, consisting of an axis bearing flowers in the axils of persistent scales; often used widely to include "cones" of all kinds. **Style**, the slender upper part of an ovary, bearing the stigmatic surface. **Sub-**, almost or somewhat, *e.g.* sub-orbicular. **Subulate**, awl-shaped, tapering to a fine point and round in cross section. **Succulent**, juicy or fleshy. **Sucker**, an adventitious shoot given off by an underground stem or root, growing at first horizontally and later growing into the air. **Sugars**, carbohydrates soluble in water and having a sweet taste. **Superior**, applied to the pistil of a hypogynous or perigynous flower. **Symbiosis**, a living

together, a mutually beneficial partnership between two plants—*e.g.* Mycorhizas on roots of various plants, root-nodules of Leguminosae (see **Mycorhiza, Nodule**). **Sympetalous** = **Gamopetalous. Syncarpous,** consisting of two or more united carpels. **Syngenesious,** applied to stamens which are united by their anthers, *e.g.* Composites.

Taproot, a stout main down-growing root bearing relatively thin rootlets. **Tendril,** a slender coiling organ which is sensitive to contact and is used in climbing. **Testa** = seed-coat, formed from integument of ovule. **Tetradynamous,** having six stamens, of which two are shorter than the other four. **Thalamus,** the receptacle of a flower. **Thorn,** a spine formed from a branch. **Throat,** the mouth of the tube of a gamopetalous corolla. **Torus** = **Thalamus. Transpiration,** the giving out by the leaves of water absorbed by the roots. **Tuber,** the thickened and fleshy end-part of an underground stem, or a thick fleshy root formed adventitiously.

Umbel, an inflorescence in which the flower-stalks all spring from one point, but the flowers reach about the same level. **Partial Umbels** are umbels seated on the branches of an umbel, the whole forming a **Compound Umbel. Unicostate,** having one chief vein (midrib). **Urceolate,** like a pitcher contracted at the mouth—*e.g.* corolla of Heather.

Ventral, the surface of an organ which faces towards the axis bearing the organ. **Vernation** or **Prefoliation,** the form and arrangement of leaves when in the bud. **Versatile,** applied to anthers when the filament is fixed in the middle, so that the anther can easily swing about. **Verticillate,** whorled, arranged in whorls. **Vessels,** tubes found in the wood of vascular bundles; serving to convey water from roots to other parts of plant. **Whorl,** a circle of similar organs arising at the same level from an axis. **Winged,** having flattened expansions—*e.g.* stem of Thistles, samaras, seed of Pine. **Wings,** the two lateral petals in a Papilionaceous flower. **Wood (Xylem),** the kind of vascular tissue which contains the **Vessels.**

Xerophilous, growing in, and adapted to, localities which are "physiologically dry"—*i.e.* in which plants cannot absorb much water, or in which transpiration tends to be excessive. **Xerophytes,** plants adapted to a xerophilous mode of life. **Xylem** = **Wood.**

Zygomorphic, applied to a flower which can only be bisected in one plane so as to show two similar halves.

APPENDIX III

CHARACTERS OF NATURAL ORDERS OF ANGIOSPERMOUS FLOWERING PLANTS.

THESE notes are confined to the chief Orders represented in Britain, with a few Orders represented by commonly cultivated plants. The Cohorts are given in order to show how the Orders may be arranged in groups; the classification into Cohorts is based on the system of Engler and Prantl, with some modifications suggested by Coulter and Chamberlain. This system is in many respects more natural than that of Bentham and Hooker. For further details of the orders, consult Fox (*How to find and name Flowers*), Bentham and Hooker's *British Flora*, Willis's *Flowering Plants and Ferns*. A handy *Guide to the Principal Families of Flowering Plants*, by Adams (Sealy & Co., Dublin: 1*s.* net), will be useful in finding the Order to which any of the common British or cultivated plants belong.

The following abbreviations have been used:

A, andrecium (stamens).
abs., absent.
adv., adventitious.
alt., alternate.
Brit., British Isles.
C, corolla.
Cf., compare with.
cpl., carpel.
comp., compound.
cult., cultivated.
distd., distinguished.
exc., except.
exstip., exstipulate.
flr., flower.
G, gynecium (pistil).
gen., generally.
herm., hermaphrodite.
inf., inferior.
infl., inflorescence.
K, calyx.
loc., loculus.
-loc., -locular.
opp., opposite.
P, perianth.
per., "
plac., placenta.
post., posterior.
pres., present.
rec., receptacle.
reg., regular.
repd., represented.
repg., representing.
sta., stamen.
zygom., zygomorphic (irregular).

CLASS I. **MONOCOTYLEDONS.** Embryo with one cotyledon; stem with closed vascular bundles, "scattered" in cross section; flrs. with parts in threes; leaves gen. parallel-veined.

Cohort PANDANALES. *Infl. spherical or cylindrical; flrs. naked or with per. of scales or hairs, unisexual;* $A\ 1-\infty$, $G\ 1-\infty$.

Typhaceae. Water and marsh plants; flrs. in long cylindrical spikes, upper part with ♂ flrs., lower with ♀ flrs.; per. = hairs which persist on fruit (nut). *Typha latifolia* (Great Bulrush, Reedmace) has ♂ and ♀ parts of spike continuous; *T. angustifolia* (Lesser Bulrush) has a bare space between the two parts.

Sparganiaceae. Water and marsh plants. Only genus *Sparganium* (Bur-reed). Flrs. in spherical heads; per. = scales; upper heads = ♂ flrs., A 3; lower heads = ♀ flrs., G 1 or (2).

Cohort FLUVIALES. *Water or marsh plants; flrs. hypogynous (exc. Hydrocharitaceae), cpls. gen. free; no endosperm.*

Potamogetonaceae. Submerged plants; flrs. gen. with "perianth" formed by scales growing from the stamens; G 1 – 4; nuts. *Potamogeton* (Pondweed) has many species and varieties in Brit., *P. natans* (with large oval floating leaves) being the commonest. *Zostera* (Eel-grass, Grass-wrack), with long narrow leaves, grows in estuaries.

Juncaginaceae. Marsh; leaves linear; flrs. herm., in racemes; per. 3 + 3, green; A 3 + 3, G (3 + 3), stigmas brushlike; protogynous, wind-pollinated; splitting-fruit. *Triglochin palustre* (Arrow-grass) in meadows; *T. maritimum* in salt marshes, with fleshy leaves.

Alismaceae. Water or marsh; K 3, C 3, $A\ 6-\infty$, $G\ 6-\infty$; achenes. *Alisma plantago* (Water Plantain) and *Sagittaria* (Arrow-head) are fairly common by sides of streams.

Butomaceae. Water; infl. a cymose umbel, K 3, C 3, $A\ 9-\infty$, $G\ 6-\infty$; ovules scattered over inner wall of each cpl.; follicles. *Butomus* (Flowering Rush).

Hydrocharitaceae. Water; flrs. unisexual, K 3, C 3; A 3 – 12; G (2 – 15), inf., 1-loc., ovules ∞; capsule. *Hydrocharis* (Frog's-bit); *Elodea* (Canadian Water-weed, introd. into Brit.).

Cohort GLUMALES. *Flrs. in spikelets, per. 0 or repd. by scales or hairs, enclosed by dry bracts (glumes); A 2 or 3, ovary 1-loc., with 1 ovule; wind-pollinated, stigmas feathery; endosperm pres.*

Graminaceae. Stem gen. hollow (rarely solid), leaves gen. with split sheath, per. 0 or repd. by "lodicules," anthers versatile, stigmas 2 rarely (1). Grasses and Cereals (see pp. 262-5). The chief Cereals are Wheat, Oats, Barley, Rye, Maize, Rice, Millet. The Bamboos (*Bambusa*) are tropical plants of great economic importance; they have branched rhizomes, which grow below the soil, and in the rainy season send up numerous erect, perennial shoots. The latter grow rapidly, reach a height of 100 ft. or more; the stem—diameter about 1 ft.—is hollow, but has partitions at the nodes, and is very hard, owing to silica in cell-walls of vessels and fibres. The stems, entire or split, are used for building and for making pipes, gutters, floats, beehives, umbrellas, hats, etc.; the leaf-sheaths for making paper; the young shoots and the seeds for food. The Sugar-cane

(*Saccharum*) resembles Bamboos in habit, but the erect shoots are shorter (about 10 ft.) and thinner (diameter 2 in.); the sugar is contained in the soft central tissue ("pith") of the stems, or "canes," which are cut before flowering occurs (why?) and crushed to extract the sap. The Sugar-cane is, in cultivation, propagated by planting cut pieces of shoot each bearing a bud.

Cyperaceae. Stem solid or hollow, often triangular, leaves with closed sheath, per. gen. repd. by scales or hairs, anthers not versatile, stigmas 3 or 2. Sedges, Cotton-grass.

Cohort PALMALES. *The only Order is—*

Palmae. Chiefly tropical; stem gen. unbranched, with a crown of large, fan-shaped, or pinnate leaves, and either very short (*Nipa*, *Phytelephas*, etc.) or tall and thin (*Livistona*, etc.), sometimes very slender and climbing (*Calamus*); the stem-base is often thickened, or else propped up by "buttress-roots." The leaf-blade shows xerophilous features, being often corrugated, covered with thick cuticle (gen. with a layer of wax), and gen. placed in a vertical plane by the petiole being slanted or twisted. Infl. sometimes terminal, and then gen. causing the plant's death, more often axillary; it is a spadix, gen. much branched, enclosed in a spathe of several leaves; flrs. gen. unisexual (herm. in *Livistona*, etc.), the ♂ and ♀ flrs. either on same or different plants; P 3 + 3, A 3 + 3, G 3 or (3); hypogynous, gen. regular; cpls. each with 1 ovule; fruit a berry (*e.g.* Date) or drupe (*e.g.* Coco-nut).

Cohort ARALES. *Infl. a simple spadix, gen. enclosed in a spathe; flrs. often naked and reduced.*

Araceae. Flrs. with parts in threes or twos, but often much reduced; berry; chiefly tropical. *Arum* (Cuckoo-pint) with reduced unisexual flrs., and *Acorus* (Sweet Flag) with herm. flrs., per. = 6 scales, A 6, G (2 – 3), in Brit.

Lemnaceae. Small floating plants, with green flat shoots bearing long unbranched roots. *Lemna* (Duckweed); in *L. minor*, the commonest species, the flrs. (often produced but inconspicuous) arise in a groove at edge of shoot, protected by a small spathe, forming a group of 2 ♂ flrs. (each = 1 sta.) and 1 ♀ flr. (1 cpl.).

Cohort FARINALES. *Flrs. with parts in threes as in next Cohort, but A often 3 or reduced to 1; endosperm mealy, not fleshy or horny as in Liliales.*

Bromeliaceae. Tropical America; mostly epiphytes with short stem bearing a rosette of leaves which have gutter-like bases, holding water; leaves fleshy, with thick cuticle. Infl. racemose, gen. with coloured bracts; K 3, C 3, A 3 + 3; G (3); sup. or inf., 3-loc. Fruit gen. a capsule, with seeds often winged, or a berry; in Pineapple (not epiphytic), after fertilisation the whole infl. (axis, flrs., bracts) becomes fleshy, and the axis grows on and produces a tuft of green leaves above it.

Commelinaceae. Herbs with alt. sheathing leaves; infl. like that of Boraginaceae (fig. 114); flrs. reg., gen. blue; K 3, C 3, A 3 + 3,

but some sta. often abs. or sterile; $\bar{G}$ (3), 3-loc.; capsule. In *Commelina* the upper 3 sta. have their anthers converted into fleshy nectaries; in *Tradescantia* (Spiderwort) the 6 sta. are fertile, and are covered with hairs, in whose cells circulation of protoplasm can be observed.

Cohort LILIALES. *Flrs. gen. with P 3 + 3, A 3 + 3, G (3); hypo- or epigynous; endosperm pres.*

Juncaceae. Per 6, scaly; A 6, rarely 3; G (3); style with 3 brush-like stigmas; protogynous, wind-pollinated. *Juncus* (Rush); *Luzula* (Wood-rush).

Liliaceae. Flr. reg.; per. 3 + 3, petaloid; A 3 + 3, G (3); some have parts in fours; fruit a capsule (rarely a berry). See pp. 258-9.

Amaryllidaceae. Like Liliaceae, but flrs. epigynous, sometimes zygom.; per. sometimes with a corona (see p. 259). Most are tropical or sub-tropical in dry climates, and many perennate by bulbs, producing leaves only in the wet season. Some have rhizomes, bearing either short erect stems with rosettes of fleshy leaves, *e.g. Agave* (edge of leaf gen. has spines; infl. very large; vegetative reproduction by suckers, and by bulbils that replace flrs.), or long stems with small leaves, *e.g. Alstroemeria* (each leaf twisted through 180° at its base), *Bomarea* (mostly climbers), *Anigozanthos* (flrs. transversely zygomorphic, cf. Fumitory).

Dioscoreaceae. Climbing herbs or shrubs; leaves net-veined, gen. sagittate or cordate; flrs. in racemes, unisexual; P 3 + 3; A 3 + 3; $\bar{G}$ (3), ovary 3-loc.; capsule or berry. Repd. in Brit. only by *Tamus* (Black or Red Bryony).

Iridaceae. Leaves 2-rowed, equitant; flr. reg. (rarely zygom.); P 3 + 3; A 3, extrorse; $\bar{G}$ (3), 3-loc.; stigmas petaloid; capsule. *Iris pseudacorus* (Yellow Flag); *I. foetidissima* (Roast-beef Plant, purple flrs.).

Cohort ORCHIDALES.

Orchidaceae. Tropical forms chiefly epiphytic, often with aerial roots; many British Orchids have tubers (adv. roots). For details of flrs. etc., see Ch. VI.

CLASS II. **DICOTYLEDONS.** Embryo with two cotyledons; stem with open bundles, usually in one ring; leaf net-veined; flrs. with parts in twos, fours, or fives, rarely in threes.

SERIES A. *Archichlamydeae.* Perianth either absent, or in one whorl (sepaloid or petaloid), or in two whorls (the parts of the inner free); sometimes one whorl is missing owing to suppression, and occasionally the inner whorl (corolla) is united (e.g. *Cotyledon*, the Wall Pennywort).

Cohort MYRICALES. *The only Order is—*

Myricaceae. Only genus *Myrica*. *M. gale*, the Sweet Gale, or Bog Myrtle, is a shrub, common in bogs; flrs. dioecious, in catkins, opening in spring before the leaves appear; no per., A 4; G (2) with 1 ovule, styles 2; nut.

Cohort SALICALES. *The only Order is—*

Salicaceae. Shrubs or trees; only genera *Salix* (Willows) and *Populus* (Poplars); flrs. dioecious, in catkins; A 2 – 30; G (2), 1-loc., ovules ∞; capsule 2-valved; seed with a basal tuft of hairs.

Cohort FAGALES. *Trees, gen. with mycorhiza on roots; flrs. unisexual, monoecious, gen. with sepaloid per.; no endosperm. For details of flrs., etc., see Ch. VI. and Ch. IX.*

Betulaceae. Ovary 2-loc., 1 ovule in each; nut winged (samara) in Birch; in Hazel and Hornbeam there is a leafy cupule. *Betula* (Birch), *Corylus* (Hazel), *Carpinus* (Hornbeam), and *Alnus* (Alder) in Brit.

Fagaceae. Chiefly distd. from Betulaceae in having ovary 3-loc., each with 2 ovules; nuts enclosed by a woody cupule. *Quercus* (Oak), *Fagus* (Beech), *Castanea* (Spanish Chestnut, not native), have respectively 1, 2, and 3 nuts in each cupule.

Cohort URTICALES. *Flrs. in cymes, parts gen. in twos, G* 1 *or* (2), *with* 1 *ovule.*

Ulmaceae. Trees. *Ulmus* (Elm), the only British genus, has per. 4 or 5, sepaloid; A 4 or 5 opp. per-lobes; G (2), 1-loc.; samara. See Ch. VI. and Ch. IX.

Moraceae. Mostly trees or shrubs. Repd. in Brit. by *Humulus* (Hop), which has dioecious protogynous wind-pollinated flrs., ♂ flrs. in panicles, per 5, A 5; ♀ flrs. in cones, 2 flrs. to each bract, G (2), 2 long stigmas; achenes with adhering bract. Here belong *Morus* (Mulberry), *Ficus* (Fig, India-rubber Plant), *Cannabis* (Hemp), etc.

Urticaceae. Infl. cymose, flrs. unisexual; per. 4 or 5; A 4 or 5, bent inwards at first and uncoiling explosively when ripe; G 1; nut enclosed in per. *Urtica* (Stinging Nettle) has opp. leaves and stinging hairs; *U. dioica* (Common Nettle) is dioecious, but *U. urens* (Small Nettle) and *U. pilulifera* (Roman Nettle) are monoecious. *Parietaria* (Wall Pellitory) has flrs. like *Urtica*, but alt. leaves and no stinging hairs.

Cohort SANTALALES. *Parasitic herbs or shrubs; G* (2 – 3), 1-*loc. in British species.*

Loranthaceae. Repd. in Brit. by *Viscum* (Mistletoe), a parasitic evergreen shrub, with opp. leaves; flrs. dioecious, per. 4-lobed, A 4, opp. per.-lobes; $\bar{G}$, with 1 style; berry.

Santalaceae. Repd. in Brit. by *Thesium* (Bastard Toadflax), a herbaceous green root-parasite; flrs. in racemes; per. 4 or 5; A 4 or 5, opp. per.-lobes; $\bar{G}$ with 1 style; nut.

Cohort ARISTOLOCHIALES. *The only Order is—*

Aristolochiaceae. Repd. in Brit. by *Asarum europaeum*, a perennial herb with stout rhizome, sending up annually several scales, 2 green leaves, 1 flr.; leaf reniform, stalk long; flrs. solitary on short stalks; per. bell-shaped, reg., 3-lobed, persistent; A 12, anthers extrorse; G inf. or semi-inf., 6-loc., ovules ∞; styles 6,

curved outwards; capsule; flr. protogynous, visited by flies, which are detained in the flr. by the per.-lobes being at first bent inwards until the anthers open. The "prison-mechanism" (cf. *Arum*, Ch. VI.) is more fully developed in *Aristolochia*; *A. clematitis* (Birthwort), an escape from cultivation; *A. sipho* (Dutchman's Pipe) is often cultd.; they are mostly climbers with twining stems; per. tubular, hooded above and enlarged below; sta. and style carried up on a column (*gynostemium*, cf. Orchidaceae) with 6 sessile extrorse anthers below and 6 apparent stigmas above (these are really anther-connectives fused to the style and acting as stigmas); ovary inf., 3-loc., ovules ∞; capsule; flr. protogynous, pollinated by flies (detained in *A. clematitis* by hairs inside per. which are easily bent downwards, but not upwards, until pollen is shed on the flies), but self-pollination occurs in many cases.

Cohort POLYGONALES. *The only Order is—*

Polygonaceae. Mostly herbs; leaves usually with ochrea; flr. reg., per. 5 or 6, sepaloid or petaloid, A 5 to 9, G̲ 1-loc. with 1 ovule, styles 2 or 3; per. often persistent around fruit (a 3-sided nut, with endosperm). *Rumex* (Docks and Sorrels), of which *R. acetosa* and *R. acetosella* are dioecious; *Polygonum* (Knot-grass, Bistort).

Cohort CENTROSPERMALES. *Mostly herbs; no stipules; A gen. = and opp. per.-lobes; G̲ 1 – ∞, gen. 1-loc. with 1 – ∞ ovules; perisperm pres., embryo coiled.*

Chenopodiaceae. Leaves fleshy, often with mealy surface; flrs. small, green; per. 2 to 5, sepaloid, persistent; A = per.-lobes, or reduced to 1; G̲ (2 or 3), ovary rounded and 1-loc. with 1 ovule, stigmas 2 or 3; nut. Mostly coast and salt-marsh plants (Beet, Marsh Samphire, Saltwort, Sea-blite, Orache); *Chenopodium* (Goose-foot) is common on waste or cultivated ground.

Caryophyllaceae. For habit and flrs., see Ch. VI.; fruit gen. a capsule opening by twice as many apical teeth as there are styles. Well repd. in Brit.

Cohort RANALES. *Flr. spiral or in whorls, sometimes zygom., gen. hypogynous; A often ∞; G gen. apocarpous, ∞ to 1.*

Order Nymphaeaceae. Water-plants with large floating leaves; per. ∞, mostly of petaloid leaves; A ∞; G ∞, superior in *Nuphar*, but sunk in rec. in *Nymphaea*; ovules scattered over inner wall of each cpl.; fruit gen. a berry; seed contains copious perisperm, with small embryo at one end surrounded by endosperm. *Nymphaea* (White Water-lily), *Nuphar* (Yellow Water-lily, or Brandy-bottle), in Brit.

Ceratophyllaceae. Only genus *Ceratophyllum* (Water Hornwort); rootless submerged water-plants with whorls of divided leaves; flrs. monoecious, with sepaloid per. (about 10 lobes); A 12 – 16; G 1, 1 ovule; achene.

Ranunculaceae. Well repd. in Brit.; mostly herbaceous perennials with alt. leaves (*Clematis* is a woody climber with opp. leaves);

flr. gen. reg. (zygom. in *Aconitum* and *Delphinium*); per. gen. petaloid, rarely with distinct green K and coloured C; A ∞, extrorse; G ∞ or few, apocarpous (exc. *Nigella*), 1 in *Actaea*; achenes, follicles, capsule (*Nigella*), berry (*Actaea*).

Berberidaceae. Repd. in Brit. by *Berberis vulgaris* (Barberry), a shrub with some leaves reduced to 3-rayed spines; K 8 or 9; C 6; A 6; G 1, with 2 ovules; berry. *Mahonia* (cult.) has broad leaves with spiny margins.

Cohort RHOEADALES. *Flr.-parts in whorls (sta. sometimes spiral), hypogynous, K and C distinct, G (∞ to 2).*

Papaveraceae. Flrs. hypog. (exc. a few foreign types, *e.g. Eschscholtzia*); K 2, caducous; C 2 + 2; A 4 or ∞; G (2 – ∞), 1-loc. with ∞ ovules on projecting parietal placentas; capsule or nut. In Poppy (*Papaver*) and its allies, *e.g. Glaucium* (Sea Horned Poppy) and *Chelidonium* (Greater Celandine), the flr. is reg. and the sta. ∞; in Fumitory (*Fumaria*) and its allies, *e.g. Corydalis* and *Dicentra* (= *Dielytra*, "Bleeding Heart," cult.), the corolla is spurred and the sta. 2 (each branched into 3 parts).

Cruciferae. See Ch. VI. for flr. and Ch. VII. for fruit. Well repd. in Britain, and easily recognised by the racemose infl., cross-like corolla, and characteristic fruit (siliqua or silicula)

Resedaceae. Chief genus *Reseda* (Mignonette). Flrs. in racemes, zygom.; rec. forms a honey-disc on upper side of flr.; K 4 – 8, C 3 – 8, A ∞, G (2 – 6); ovary open at top, 1-loc.; capsule.

Cohort SARRACENIALES. *Herbs with entire insectivorous leaves; flr.-parts gen. in whorls, hypogynous, reg.; $\underline{G}$ (3 – 5), ovules ∞; endosperm pres. (see. Ch. VIII.).*

Sarraceniaceae (*Sarracenia*, *Darlingtonia*) and **Nepenthaceae** (*Nepenthes*) are foreign orders of Pitcher-plants, often cultd. in greenhouses.

Droseraceae includes *Drosera*, *Dionaea*, etc., mostly with sticky hairs. Repd. in Brit. by *Drosera* (Sundew); flrs. in cymes, reg.; K (4 – 8), C 4 – 8, A gen. 5, G (2 – 5), 1-loc.; gen. self-pollinated.

Cohort ROSALES. *Flr.-parts in whorls, with distinct K and C, or apetalous; hypo-, peri-, or epigynous; G 1 – ∞, free or united. The orders are closely connected with each other, with wide range of floral structure, and the Cohort is hard to define.*

Crassulaceae. Leaves gen. fleshy; flrs. in cymes, reg.; K_n C_n A_{n+n}, $\underline{G}$ n (n = 3 up to 30); cpls. often slightly united at base, each cpl. with a honey-scale below it on outer side; ovules ∞; flrs. gen. protandrous, visited chiefly by flies; follicles; no endosperm. *Sedum* (Stonecrop, Orpine) has n = 5; *Sempervivum* (Houseleek) has n = 6 to 20; *Cotyledon* (Wall Pennywort) has the petals united.

Saxifragaceae. Very closely allied to Crassulaceae and to Rosaceae. K gen. 5, C 5 or 0, A gen. 5 + 5, G gen. < C and always united; ovules ∞; capsule or berry; endosperm abundant. *Saxifraga* (saxifrages) has gen. K 5; C 5; A 5 + 5; G (2), 2-loc.

Chrysosplenium (Golden Saxifrage) has no petals, K 8 or 10, ovary 1-loc. *Parnassia* has 5 sta. and 5 branched staminodes, ovary 1-loc., stigmas 3 or 4. *Ribes* (Currants, Gooseberry) has K (4 or 5) forming a tube on which are inserted the small petals and the sta.; $\bar{G}$ (2), 1-loc.

Rosaceae. Very closely allied to Saxifragaceae and to Leguminosae (sub-order Mimoseae). Well repd. in Brit. Leaves gen. alt. and stip., often comp.; flrs. reg., perigynous; K 4 or 5, if 5 the odd lobe is posterior; C 4 or 5, rarely abs.; A often ∞; G gen. ∞, distinct in bud at any rate; rec. gen. forms part of the fruit; little or no endosperm; fruit various, characters used in classification into Sub-orders.

SUB-ORDERS represented in Britain:

Pruneae. Fruit a *drupe* (Cherry, Sloe, Cherry Laurel, Almond).

Rubeae. Fruit an etaerio of *small drupes* (Blackberry, Raspberry).

Spiraeae. Fruit an etaerio of *follicles* (Meadow-sweet).

Potentilleae. Fruit an etaerio of *achenes* on a dry or fleshy receptacle (Avens, Cinquefoil, Strawberry).

Poterieae. Fruit of one to three *achenes* enclosed in dry concave receptacle (Lady's Mantle, Agrimony, Salad Burnet).

Roseae. Fruit of many *achenes* in deep fleshy hollow receptacle (Rose).

Pomeae. Fruit a *pome* (Apple, Pear, Hawthorn).

Leguminosae. The second largest Order of flowering plants, with 7,000 species (cf. Compositae); mostly erect plants, but often climbers with twining stems, leaf-tendrils, stem-tendrils (*Bauhinia*, etc.), hook-like leaves (*Caesalpinia*, etc.), hooked emergences (some Acacias); some are "lianas," with flat, twisted, or corrugated stems. Infl. gen. racemose; flrs. zygom. (exc. Mimoseae), G 1; fruit gen. a pod or lomentum. There are three Sub-orders, which should perhaps rank as independent Orders.

(1) **Papilionaceae.** Well repd. in Britain (pp. 242-4). In Clovers, Sainfoin, Melilot, etc., the fruit is indehiscent, and has only 1 or 2 seeds; in Medicks the pod is curved or coiled up, and often covered with hooks; in *Astragalus* it is 2-chambered, having a longitudinal partition; in *Ornithopus* and *Hippocrepis* it is a lomentum, breaking across into 1-seeded parts. Notable tropical genera are: *Bossiaea* and *Carmichaelia* (Australia), with flat green cladodes; *Dalbergia*, some species of which climb by special short branches, others by the leaf-base (pulvinus) coiling round a support (the leaflets then falling off); *Colutea*, with bladder-like pods; *Pterocarpus*, with winged pods; *Sophora*, *Toluifera*, etc., have the stamens free.

(2) **Caesalpineae.** Mostly tropical; flr. zygom., but the 5 petals overlap each other *from below upwards*; sta. 5 to 10, rarely ∞, sometimes opening by pores. Notable genera: *Bauhinia*; *Cercis* (Judas-tree, often cult. in Brit.); *Ceratonia* (Carob-tree, pods containing sugary pulp); *Cassia*, whose flr.

has the 3 upper sta. sterile or absent, while the 2 lowest are longer than the other 5, and project either to right or left; *Gleditschia* (tree, cult. in Brit.), with branched thorns in leaf-axils; *Tamarindus*, in which the lower petals = bristles, the 3 fertile stamens united, and the pod contains edible pulp.

(3) **Mimoseae.** Tropical and sub-tropical plants; flr. reg.; K 4, C 4, A 4 or ∞. The chief genera are *Acacia* and *Mimosa.* The former consists chiefly of trees, typically with bipinnate leaves, ∞ leaflets, scaly stipules, but about two-thirds of the species, living chiefly in Australia, have phyllodes (see p. 225), and many have stipules = thorns. The species of *Mimosa* occur chiefly in America, but *M. pudica* has spread throughout the tropics as a weed. *Calliandra*, sometimes cult., has the ∞ stamens united. *Neptunia*, a water-plant with floating stem covered by spongy tissue, has sensitive leaves like those of *Mimosa.*

The only absolute floral distinction between Leguminosae and Rosaceae is in the calyx, the odd sepal being anterior in L. and posterior (nearest the axis of infl.) in R., but both Orders have plants with a 4-lobed calyx, so even this distinction breaks down.

Cohort GERANIALES. *Mostly herbs; flr.-parts in whorls; flr. reg. in all British genera exc. Polygala; parts gen. in fives; cpls. united, each gen. with* 1 *or* 2 *ovules, and gen. splitting apart when ripe.*

Geraniaceae. Leaves gen. toothed or lobed; K 5, C 5, A 5 + 5 or 5 (*Erodium*); G gen. (5) with 1 or 2 ovules in each loc., style long with 5 stigmas; protandrous; fruit splits into 5 1-seeded parts, which separate elastically from the persistent style. *Geranium* (Crane's-bill, several species) and *Erodium* (Stork's-bill) in Brit. In *Pelargonium* (Garden Geranium) there is a cavity at top of flr.-stalk, repg. a spur of post. sepal.

Oxalidaceae. Repd. in Brit. by *Oxalis* (Wood Sorrel); leaf with 3 leaflets; flr. reg.; K 5; C 5; A 5 + 5 with bases of filaments united to a tube; G (5), styles free, several ovules in each loc.; capsule; seed with fleshy aril, which by its sudden inversion shoots out the seed.

Tropaeolaceae. *Tropaeolum* (Garden Nasturtium, cult.) has twining petioles; flr. zygom.; K 5, post. sepal with a spur (cf. *Pelargonium*); C 5, the 3 ant. petals with hairs; A 8, 4 on each side of middle line; G (3), 3-loc., 1 ovule in each; fruit splits into 3 nuts.

Linaceae. Leaves entire; flr. reg., gen. K 5; C 5; A 5, 10, or more; G gen. (5) with free styles, each loc. divided into 2 by a vertical partition; cpls. split apart into 2-seeded parts. *Linum usitatissimum* (Flax, Linseed) occurs as an escape from cult., but 3 species (*L. perenne*, *L. catharticum*, *L. angustifolium*) grow wild, with smaller flrs. *Radiola* (all-seed) differs chiefly from *Linum* in having flr.-parts in fours and the styles united.

Rutaceae. Chiefly in S. Africa and Australasia, some in Europe, but none in Brit.; mostly shrubs and trees, often xerophilous; leaves

gen. compound, with oil-glands. Infl. gen. cymose; flr. gen. herm.; $K_n C^n A_{n+n} G(n)$, with n = 5 or 4, but sta. and cpls. may be reduced in number or may be ∞. The Order is divided into several sections, the chief ones being Ruteae and Aurantieae.

Ruteae. Cpls. often separate when ripe; fruits sometimes drupes, never berries. *Ruta* (Rue), cult. in Brit.; flrs. reg., end flr. of infl. has parts in 5's, lateral flrs. have parts in 4's. *Dictamnus* (Dittany) has zygom. flrs. *Diosma*, resembling Heathers in habit, and *Boronia* are often cult.

Aurantieae. Fruit a berry, with pulp formed by juicy hairs growing in from carpels. Chief genera *Citrus* and *Limonia*, with simple leaves; A ∞, in several bundles; G (∞); there are often short branches whose leaves = thorns. Oranges, lemons, etc., are fruits of species and varieties of *Citrus*.

Polygalaceae. Repd. in Brit by *Polygala* (Milkwort); flrs. zygom.; K 5, 2 sepals broad and petaloid, the other 3 narrow and green; C gen. 3, ant. petal keel-like and crested, and united to a tube with the 2 smaller side-petals; A 4 + 4, united into a split tube adhering to petals, anthers open by pores; G (2), 2-loc., each with 1 ovule; floral mechanism somewhat like that of Papilionaceae, though the structure is of course quite different.

Euphorbiaceae. A large Order, repd. in Brit. only by *Euphorbia* (Spurge, several species) and *Mercurialis* (Dog's Mercury, 2 species, the commoner one perennial, the other annual). *Mercurialis* has small green flrs., gen. dioecious, per. 3-lobed; A 8 – 20; Ḡ (2), 2-loc., each with 1 ovule, 2 long styles. *Euphorbia* has milky juice, flrs. in a peculiar infl. (fig. 115), consisting of a central stalked ♀ flr. with several ♂ flrs. (each = 1 sta. on a stalk) around it; G (3), 3-loc., 3 forked stigmas. The cpls. separate when ripe, and each opens to let the seed escape.

Callitrichaceae. Only genus *Callitriche* (Water Starwort), gen. submerged; leaves opp. entire, upper ones forming a rosette; flrs. monoecious, no per., but with 2 bracts; ♂ = 1 sta.; ♀ = 4-loc. ovary with 2 styles (cf. Labiatae), 1 ovule in each loc.; fruit splits into 4 parts.

Cohort SAPINDALES. *Closely allied to Geraniales, and only separated by a trivial but constant difference in the position of the ovules in the ovary.*

Buxaceae. Repd. in Brit. by *Buxus* (Box), an evergreen shrub with simple opp. leaves; flrs. monoecious in axillary clusters, the upper ones ♀; ♂ flr. has per. 4 (sepaloid), A 4 opp. sepals; ♀ flr. has per. 4 – 12, ovary 3-loc., 3 styles; capsule.

Empetraceae. Repd. in Brit. by *Empetrum nigrum* (Crowberry), a heather-like shrub on moors; leaves alt. exstip., linear, with margins rolled back to form a tube, opening by a slit (fringed with hairs) on lower surface; flrs. gen. dioecious, wind-pollinated, in clusters on special short branches; per. 3 + 3, scaly; A 3 or 4, filaments long; G̲ (2 – 9), styles short, ovary 2 – 9-loc. each with 1 ovule; drupe.

Celastraceae. Repd. in Brit. by *Euonymus europaeus* (Spindle-tree); leaves opp. with caducous stipules; flrs. small, in axillary clusters; K (4); C 4; A 4 (alt. with C); G (4) sunk in fleshy disc from which petals and sta. arise; ovary 4-loc., 2 ovules in each loc., style simple; fruit a red 4-lobed capsule opening at angles and exposing the seeds; seed with fleshy orange-coloured aril.

Ilicaceae. Repd. in Brit. by *Ilex aquifolium* (Holly); flrs. gen. dioecious, ♂ with barren pistil, ♀ with barren sta.; K 4; C 4; A 4; G (4), 4-loc. drupe with several seeds.

Aceraceae. Repd. in Brit. by *Acer campestre* (Common Maple) and *A. pseudoplatanus* (Sycamore), the former with leaf-margin smoothly lobed and flrs. in erect corymbs, the latter with leaves larger and the lobes pointed and toothed and the flrs. in loose hanging racemes. Trees with opp. exstip. leaves, flrs. green, reg.; K 5; C 5; A 4 + 4 on a honey-disc; G (2), 2-loc. each with 2 ovules (cpls. sometimes 3); protandrous, insect-pollinated; fruit splits into 2 (or 3) samaras (wings spreading horizontally in Maple, diverging to form a right angle in Sycamore).

Hippocastanaceae. Only genus is *Aesculus* (Horse-chestnut, cult.); see Ch. IX. Infl. a raceme of cymes; upper flrs. are ♂ with barren pistil, and open first; lower flrs. herm. and protogynous; K (5); C 5 or 4, zygom.; A from 8 to 5, on a honey-disc; G (3), 3-loc. with 2 ovules in each loc.; pollinated by bees; capsule leathery and spiny, 3-valved, with 1 seed.

Balsaminaceae. Repd. in Brit. by *Impatiens noli-me-tangere* (Yellow Balsam, rare; many species cult.), annual herb with fleshy stem, leaves alt.; flr. zygom. with stalk twisted through 180° (cf. Orchids); K 5, the 2 ant. small or abs., the post. one spurred, all petaloid; C 5, the lateral ones united in pairs; A 5, anthers cohering around pistil; G (5), 5-loc. with ∞ ovules; stigmas 5, small; capsule bursts into 5 valves which roll up inwards and scatter the seeds.

Cohort RHAMNALES. *Flr. reg., parts in whorls; sta. = and opp. petals; G (5 – 2) each with 1 or 2 ovules.*

Rhamnaceae. Repd. in Brit. by *Rhamnus cathartica* (Common Buckthorn), with leaves serrate; flrs. dioecious in dense clusters; K 4; C 4; A 4; and *R. frangula* (Alder Buckthorn) with entire leaves, flrs. in small clusters (2 or 3); herm.; K 5; C 5; A 5. In both, the petals are small, G (3 or 4) with 1 erect ovule in each loc.; fruit a drupe.

Vitaceae. Not repd. in Brit., but species of *Vitis* and *Ampelopsis* (Vine, Virginian Creeper) are commonly cult.; mostly climbers; K (4 or 5) very small; C 4 or 5, caducous; A 4 or 5; G (2) with 2 erect ovules in each loc.; berry.

Cohort MALVALES. *Flr.-parts in whorls; K 5; C 5; A ∞; G (2 – ∞), each with 1 or 2 ovules.*

Tiliaceae. *Tilia* (Lime-tree), repd. in Brit. by *T. parvifolia* (a doubtful native; other species commonly cult.), has flrs. in cymes with a leaf-like bract adhering to stalk of infl.; K 5; C 5 A ∞ united at base into several bundles; G (5); nut.

Malvaceae. Flrs. gen. with epicalyx; K 5; C 5; A ∞ (by branching) and monadelphous; G̲ (∞) with long style and ∞ stigmas; cpls. separating as nuts when ripe. *Malva*, etc. (Mallows), in Brit.; *Abutilon*, Hollyhock, etc., are cultivated. In *Malope* the ∞ cpls. are divided by horizontal partitions, producing vertical rows of chambers each with 1 ovule. *Pavonia* has 10 styles, but only 5 cpls. develop; when ripe the cpls. are hooked. In *Hibiscus* there are 5 teeth at the top of the stamen-tube, probably repg. the outer whorl of stamens, which is not developed in rest of Order; fruit a capsule. *Gossypium* (Cotton-plant) has a capsule; the seeds contain oil, and are covered with long hairs for wind-dispersal.

Cohort PARIETALES. *Flr.-parts in whorls; A often ∞; hypo- to epigynous; G (2 – ∞), gen. with parietal placentas.*

Dilleniaceae. Chiefly Australian xerophytes (in the "scrub" vegetation); infl. cymose; K 5, 4, 3, or ∞; C 5, A ∞, G ∞ – 1 with 1 – ∞ ovules. The spiral arrangement and indefinite number of flr.-parts connect this Order with Ranales. Chief genus ***Hibbertia***, some species resembling Heathers, others are climbers, some have cladodes.

Tamaricaceae. Repd. in Brit. by *Tamarix gallica* (a doubtful native on south and east coasts), an evergreen shrub with small linear leaves; flrs. in spikes, white or pink; K 4 or 5; C 4 or 5; A 4, 5, 8, or 10, on a disk with 10 glands; G (2 – 5); capsule 2 – 5-valved.

Frankeniaceae. Repd. in Brit. by *Frankenia laevis* (Sea-heath, in salt marshes on south and east coasts), a perennial with wiry branches and small rolled-up leaves; flrs. small; K 4 or 5; C 4 or 5; A 4 to 8; G (3); ovary 1-loc., ovules ∞; capsule.

Cistaceae. Repd. in Brit. by *Helianthemum* (Rock-rose), small shrubs with opp. leaves; K 3; C 5; A ∞; G (3); ovary 1-loc.; capsule 3-valved.

Hypericaceae. Repd. in Brit. by *Hypericum* (St. John's Wort, several species); leaves opp., often with oil-glands; flrs. in cymes, reg., yellow; K 5; C 5; A ∞, united at bases into 3 or 5 bundles; G̲ (3 – 5), 1- or 3 – 5-loc., ovules ∞; capsule; flrs. honeyless, but visited by various insects for pollen (cf. Poppy, Rock-rose, etc.).

Violaceae. Repd. in Brit. by several species of *Viola* (Violet, Pansy); leaves alt., stip.; flrs. zygom. (see Ch. VI.); capsule opening by 3 valves.

Passifloraceae. Chief genus is *Passiflora* (Passion-flower, cult.), climbers with axillary tendrils and alt. stip. leaves; flr. reg.; K 3 – 5; C 3 – 5; A 3 – 5; G̲ (3), 1-loc., ovules ∞; berry. The rec. is hollowed, and carries on its margin the sepals and petals and ∞ long petaloid outgrowths; it also grows up in the centre, and carries the sta. and pistil on the top of a column.

Begoniaceae. Chief genus is *Begonia* (cult.); leaves alt. stip.; blade lopsided at base; flrs. in cymes; ♂ flr. has per. 2, petaloid, A ∞; ♀ flr. has per. 2 – 5, Ḡ (2 or 3), ∞ ovules on axile placentas, ovary winged; capsule.

Cohort OPUNTIALES. *The only Order is*—

Cactaceae. Several genera cult.; chiefly desert-plants with fleshy stems; flrs. large, with ∞ per.-leaves showing transition from sepals to petals; A ∞ epipetalous; $\bar{G}$ (4 – ∞), 1-loc., ovules ∞; berry.

Cohort MYRTALES. *Flrs. peri- or epigynous, flr.-parts in whorls, G gen.* (2 – 4).

Thymelaeaceae. Repd. in Brit. by *Daphne laureola* (Spurge-laurel, evergreen, flrs. green) and *D. mezereum* (Mezereon, deciduous, flrs. pink; a doubtful native); per. 4-lobed; A 4 + 4 inserted on per.-tube; G 1-loc., 1 ovule; drupe.

Elaeagnaceae. Repd. in Brit. by *Hippophaë* (Sea Buckthorn), a Willow-like shrub, covered with scale-hairs, shoots often ending in a spine; ♂ flrs. small, in clusters, per. (2), A 4; ♀ flrs. single in leaf-axils, per. (2), G 1-loc. with 1 ovule; false berry formed by per. becoming fleshy.

Lythraceae. Repd. in Brit. by *Lythrum* (Purple Loosestrife) and *Peplis* (Water Purslane); K (4 or 6); C 4 or 6; A 6, 8, or 12; G (2), 2-loc., ovules ∞; capsule. *Lythrum* has large red or purple flrs. with 12 stamens in 2 whorls; flrs. trimorphic heterostyled (see Ch. VI.). *Peplis* has small flrs. with petals minute or absent.

Myrtaceae. Tropical and sub-tropical trees and shrubs; leaves opp., entire, evergreen, gen. with oil-glands; flrs. in cymes, perigynous or epigynous; K (4 or 5), C 4 or 5, A ∞, G ∞ – 1-loc.; style and stigma simple, ovules 2 – ∞ in each loc., axile placentation. There are two Sub-orders: (1) Myrteae (chiefly in America), with fleshy fruits (berry or drupe); (2) Leptospermeae (chiefly in Australasia), with dry fruits (capsule or nut). To the Myrteae belong *Myrtus* (Myrtle); *Eugenia* (dried flr.-buds = cloves); *Psidium* (fruit yields guava); *Pimenta* (dried unripe fruits = allspice). To the Leptospermeae belong *Eucalyptus* (Blue-gum, etc.), in which the receptacle becomes woody in fruit; *Callistemon, Metrosideros, Melaleuca.*

Melastomaceae. A large tropical and sub-tropical Order, easily distinguished by the venation of the leaves, which are simple, entire, decussate (one leaf of each pair gen. smaller than the other); the veins spread out from base of blade and converge again at tip. Infl. cymose; flrs. perigynous; $K_n C_n A_{n+n} G(n)$ with n = 4 or 5; each anther opens by an apical pore, and there are gen. appendages on the connective; ovary 4- or 5-loc., ovules ∞, simple style and stigma; berry or capsule. Chief genera: *Medinilla, Monochaetum, Leandra.*

Onagraceae. Flr.-parts in fours or twos; ovary inf., 4- or 2-loc. Repd. in Brit. by *Epilobium* (Willow-herb, several species) with K 4, C 4, A 4 + 4, $\bar{G}$ (4), fruit a capsule, seeds with tuft of hairs (cf. Willow); *Circaea* (Enchanter's Nightshade) with K 2, C 2, A 2, G (2), fruit a nut covered with hooks; *Ludwigia* (very rare, in bogs in Sussex and Hants) with K 4, C 0, A 4, $\bar{G}$ (4). *Fuchsia* ("calyx-tube" short, berry) and *Oenothera* (Evening Primrose, "calyx-tube" long, capsule) are often cult.

Haloragidaceae. Water and marsh plants; flrs. sometimes much reduced; A 1 – 8, G 1 – 4, 1 ovule in each loc. Repd. in Brit. by *Hippuris* (Mare's-tail), with whorled narrow entire leaves, small solitary axillary flrs., flr. = 1 epigynous sta. and 1 cpl. with long feathery style; *Myriophyllum* (Water Milfoil), submerged with whorled leaves, leaf with ∞ narrow pinnate branches, flrs. small, monoecious, in spikes projecting out of the water, upper flrs. ♂ with K 4-lobed, C 4, A 2, 4, or 8, lower flrs. ♀ with K 4-lobed, C 4 or 0, G 4-loc., 1 ovule in each loc., 4 short styles.

Cohort UMBELLALES. *Flrs. gen. in umbels; A = and alt. with C, epigynous; cpls. 5 to 1 each with 1 ovule.*

Araliaceae. Repd. in Brit. by *Hedera* (Ivy); K (5), lobes minute; C 5; A 5; Ḡ (5), 5-loc.; drupe.

Umbelliferae. Well repd. in Brit.; herbs with alt. exstip. leaves, gen. with sheathing base; flrs. gen. in comp. umbels; K 5 or 0; C 5; A 5; G (2); fruit splits into two parts.

Cornaceae. Repd. in Brit. by *Cornus* (Dogwood); K (4); C 4; A 4; G (2); drupe. *Aucuba* ("Variegated Laurel"), often cult., is like *Cornus*, but dioecious.

SERIES B. *Sympetalae.* Perianth in 2 whorls, corolla united (gamopetalous) with few exceptions; sta. twice as many as petals, or as many, or reduced to 4 or 2, epipetalous in all Orders exc. Ericaceae and Campanulaceae.

Cohort ERICALES. *Flrs. reg., parts in fives or fours; sta. 10 or 8, rarely 5 or 4; petals free in some cases; hypo- or epigynous; G (2 – ∞).*

Pyrolaceae. Repd. in Brit. by *Pyrola* (winter-green, evergreen plants) and *Monotropa* (Bird's Nest, total saprophyte); flrs. hypogynous; K 4 or 5; C 4 or 5 (polypetalous); A 8 or 10; G (4 or 5), ∞ ovules in each loc.; capsule.

Ericaceae. Mostly evergreen shrubs, with mycorhiza on roots; repd. in Brit. by *Calluna* (Ling), *Erica* (Heather, several species), *Vaccinium* (Bilberry, etc.), and a few other (rare) genera; K 4 or 5; C (4 or 5); A gen. 8 or 10; G (4 or 5), ovules ∞ in each loc., axile placentation, style simple; capsule or berry; the ovary is inf. in *Vaccinium* and its allies. Stamens open by pores, and bear appendages in British genera. *Rhododendron*, *Azalea*, *Arbutus* (Strawberry-tree), etc., are often cult.

Cohort PRIMULALES. *Flrs. reg., parts in fives (rarely in fours), sta. gen. = and opp. corolla-lobes; petals sometimes free or absent; ovary 1-loc. with ∞ to 1 ovules on free central placenta.*

Primulaceae. Characters of Cohort; style single; capsule opening by teeth, or by a lid (*Anagallis*, *Centunculus*), many-seeded. Well repd. in Brit.; flrs. heterostyled in *Primula*, *Glaux*, *Hottonia*. *Glaux* (Sea Milkwort) has no petals; *Samolus* has the ovary half-inferior, and has 5 staminodes alt. with the sta.; *Lysimachia* (Yellow Loosestrife) and *Trientalis* have a rotate corolla, the latter has the

flr.-parts in sevens. *Hottonia* (Water Violet) grows submerged with much-divided leaves, flowering branches growing above the water.

Plumbaginaceae. Repd. in Brit. by *Armeria* (Thrift) and *Statice* (Sea Lavender), both coast and salt-marsh plants; K (5); C 5, free or only united at base; A 5; G (5), 1-celled with 1 basal ovule, styles free or only united at base. *Plumbago*, often cult., has united petals and united styles.

Cohort GENTIANALES. *Leaves opp.; petals gen. twisted in flr.-bud; sta. gen. = petals and alt. with them, or fewer; G (2).*

Oleaceae. Trees or shrubs; flrs. reg., in cymes; K (4); C (4); A 2; G (2); style simple; stigma 2-lobed; ovary 2-loc. with 2 ovules in each loc. Repd. in Brit. by *Ligustrum* (Privet), evergreen shrub, black berries; and *Fraxinus excelsior* (Ash-tree) with polygamous apetalous flrs., samara with twisted wing. Jasmine, Forsythia, etc., are often cult.

Gentianaceae. Flrs. in dichasia; K (5); C (5); A 5; G (2); ovary 2-loc., ovules ∞; capsule. Repd. in Brit. by *Gentiana* (Gentians, flrs. blue), *Erythraea* (Centaury, flrs. red), *Chlora* (Yellow Gentian), *Menyanthes* (Bog-bean). The last named has dimorphic heterostyled flowers.

Apocynaceae. Repd. in Brit. by *Vinca major* and *V. minor* (Periwinkles), probably not natives; perennial and shrubby, with trailing barren shoots and erect flowering shoots, milky juice; K (5); C (5), salver-shaped; A 5; G (2); style single, dilated into a disc below the stigma; cpls. only slightly joined; follicles.

Cohort POLEMONIALES. *Leaves gen. alt.; flrs. reg.; K (5); C (5); A 5 alt. with petals; G (2 or 3).*

Convolvulaceae. Characters of Cohort; G (2), 2-loc., 1 or 2 ovules in each loc.; capsule. Repd. in Brit. by *Convolvulus* (Bind-weed) and *Cuscuta* (Dodder). The chief foreign genera are *Ipomaea* (Morning Glory, Sweet Potato, Jalap) and Evolvulus. Many plants of the Order contain milky juice (latex).

Polemoniaceae. G (3), 3-loc., capsule. Repd. in Brit. by *Polemonium caeruleum* (Jacob's Ladder).

Cohort BORAGINALES *includes the Orders Boraginaceae and Hydrophyllaceae, the latter not repd. in Brit.*

Boraginaceae. Leaves alt., gen. with rough hairs; flrs. reg. (exc. *Echium*), in curved one-sided racemes; K (5); C (5); A (5); G (2), 4-loc. by formation of a septum in each cpl., 1 ovule in each loc.; fruit splits into 4 achenes (nutlets). Chief British genera: *Echium* (Viper's Bugloss) with zygom. flrs.; *Pulmonaria* (Lungwort) with dimorphic heterostyled flrs., wild only in Hants; *Borago* (Borage); *Lithospermum* (Gromwell), the common species, *L. officinale*, has white flrs.; *Anchusa* (Alkanet); *Lycopsis* (Bugloss) with corolla-tube curved; *Symphytum* (Comfrey); *Cynoglossum* (Hound's-tongue), nuts covered with hooked prickles; *Myosotis* (Scorpion-grass, Forget-me-not) with several species.

Hydrophyllaceae. Several genera are cult. in greenhouses—*e.g. Nemophila, Phacelia.* Differs from Boraginaceae in having ovary 1- or 2-loc., with ∞ to 2 ovules to each cpl.; fruit a capsule.

Cohort LABIATALES. *Leaves opp.; flrs. in cymes; K* (5); *C* (5) *zygom., A gen.* 4 (*upper sta. missing*), *ovary* 2- *or* 4-*celled, ovules* 1 *or* 2 *in each cell.*

Labiatae. Characters of Cohort; sta. in 2 pairs, or 1 pair (anterior); G (2), but ovary 4-loc. by partitions, as in Boraginaceae; 1 ovule in each loc., style arising from centre of ovary-lobes; fruit as in Boraginaceae, but nutlets never with prickles, etc.; stem square; leaves decussate. Well repd. in Brit.; *Lycopus* (Gipsy-wort) and *Salvia* (Sage, Clary) have 2 sta.; *Lamium amplexicaule* (Henbit Dead-nettle) produces, besides ordinary flrs., cleistogamic flrs. in spring and autumn; Thyme has ♂, ♀, and herm. flrs.; some Mints, Marjoram, Ground Ivy, and Self-heal have conspicuous herm. flrs. and small ♀ flrs.

Verbenaceae. Repd. in Brit. only by *Verbena officinalis* (Vervain), distinguished from Labiatae by the rounded ovary with style on top, but the fruit is similar. In other genera, however, the ovary is from 2- to 4-loc. and the fruit a berry or drupe.

Cohort PERSONALES. *Flrs. gen. zygom.*; *K* (5); *C* (5); *A* 5, 4, *or* 2; *G* (2), 2-*loc. with* ∞ *ovules in each loc.*; *fruit gen. a capsule, sometimes a berry or drupe.*

Solanaceae. Flr. gen. reg.; C 2-lipped in some foreign types; G (2) oblique with ant. cpl. to left and post. cpl. to right; fruit a berry or capsule. Repd. in Brit. by ***Hyoscyamus*** (Henbane) in waste sandy places, with sticky hairs, C yellow with purple veins, capsule opening by a lid; *Solanum* (*S. dulcamara*, Bittersweet, climbing, flrs. blue, berries red; *S. nigrum*, a weed in fields and gardens, erect, flrs. white, berries black); *Atropa* (Deadly Nightshade) in waste places, probably native on chalk soils, flrs. green-purple, berry 2-lobed. *Lycium* ("Tea-plant") is a trailing shrub, not native, but often grown in S. England in garden-hedges; *Solanum tuberosum* is the Potato; *Lycopersicum*, the Tomato. Other genera often grown are *Physalis* (Winter Cherry), with fruit enclosed by large red calyx; *Datura* (Thorn-apple), with 4-loc. ovary and 4-valved spiny capsule; *Nicotiana* (Tobacco Plant); *Petunia*; *Browallia* and *Schizanthus* have zygom. flrs. with 4 or 2 sta.

Scrophulariaceae. Difficult to separate from Solanaceae exc. by the 2 cpls. being here ant. and post. in the median line, not oblique; flrs. 2-lipped (exc. *Verbascum*); A usually 2 + 2 (didynamous), but the post. sta. pres. in *Verbascum*, repd. by a staminode in *Scrophularia*, *Linaria*, etc.; capsule. Repd. in Brit. by *Verbascum* (Mullein), *Linaria* (Toadflax), *Digitalis* (Foxglove), *Antirrhinum* (Snapdragon), *Scrophularia* (Figwort); *Veronica* (Speedwell) has K (4), C (4), A 2. *Mimulus* (Musk) grows along river sides, probably a garden escape. *Bartsia*, *Euphrasia* (Eyebright), *Rhinanthus* (Rattle), *Pedicularis* (Lousewort), and *Melampyrum* (Cow-wheat)

Cohort CAMPANALES. *Flrs. gen.; K*(5); *C*(5); *A* 5; $\overline{G}$ < 5; *anthers close together or united.*

Cucurbitaceae. Repd. in Brit. only by *Bryonia dioica* (White Bryony), a climber with tendrils and dioecious flrs. ; K (5); C (5), reg. ; A 3 (2 sta. have 4-loc. anthers, hence they probably represent 2 pairs of stamens fused together, the fifth sta. being free and with 2-loc. anther), anthers curved ; G (3), 3-loc., ovules ∞; berry red. Honey secreted inside base of corolla, flrs. visited by small bees (*Andrena*, a burrowing-bee). The fruit is long and many-seeded in Cucumber, Vegetable Marrow, etc. ; in *Ecballium* (Squirting Cucumber) it breaks off and contracts, violently squirting the seeds out of the hole thus formed ; the bath loofah is the vascular system of the fruit of *Luffa*, left after removing the soft tissue.

This Order is chiefly tropical, and consists almost entirely of annual herbaceous tendril-climbers. Flrs. unisexual, sometimes monoecious. In *Fevillea*, etc., there are 5 separate stamens with 2-loc. anthers ; in *Thladiantha*, etc., 2 pairs of sta. are set apart from the odd sta.; then through types with these pairs fused we get, by twisting of the anthers, the complex arrangement seen in Bryony, Cucumber, etc. In *Echinocystis* the anthers are all united into a column ; in *Cyclanthera* the anthers fuse to form 2 ring-like pollen-sacs running round the column, and the berry splits violently into valves, which roll outwards and fling out the seeds.

Campanulaceae. Herbs with milky juice ; flrs. gen. reg., protandrous ; K (5); C (5) ; A 5, anthers introrse and gen. cohering around the style but not epipetalous ; $\overline{G}$ (2 – 5), ovules ∞ in each loc., style simple, stigmas free ; capsule opening by slits or pores. Chief genera in Brit.: *Campanula* (Hare-bell, several species); *Jasione* (Sheep's-bit), flrs. in heads ; *Lobelia*, flr. zygom., corolla split to base on post. side, sta. epipetalous, anthers united ; *Phyteuma* (rare, S. England), flrs. in heads, C deeply divided into 5 long narrow lobes, anthers free. Note the differences between *Jasione* and *Scabiosa* (Dipsaceae). *Lobelia Dortmanni*, aquatic perennial in lakes (Ireland, west of Brit.), has tufted cylindrical hollow leaves, and spreads by runners.

Compositae. The largest Order of flowering plants, with over 11,000 species. Very few are water or marsh plants, climbers, shrubs, or trees. Flrs. in heads, which are sometimes arranged in racemes, corymbs, etc.; flrs. sessile on expanded end of infl.-stalk, with involucre of bracts; bracts or hairs often occur between the flrs.; K sometimes = a rim with 5 lobes, more often = hairs (pappus), sometimes absent; C (5) reg. (tubular) or zygom. (ligulate, rarely 2-lipped); A (5), epipetalous and with united anthers (syngenesious). The ligulate type of corolla has either 5 or 3 teeth at the end of the strap; the 2-lipped (labiate) type occurs only in *Mutisia* and a few other tropical genera. See pp. 256-8 for biology of flrs., etc.

APPENDIX IV.

HINTS ON PRACTICAL WORK.

LIKE probably most other teachers of Botany who realise that lecturing is almost useless as a means of teaching the elements of the subject, I have drawn up various set schemes for practical work based on the months of the (college) year. The scheme has been changed from year to year, but in general the first term (September to December) is devoted to the study of seeds and their germination, the naked-eye features of a "typical" plant (*e.g.* Broad Bean, Wallflower, Dead-nettle), of fruits and seeds (with special reference to dispersal), of various forms of shoot (rhizome, corn, bulb, etc.), reserve-food, structure of buds. The second term (Jan. to March) begins with lens and microscope work on seeds, roots, stems, and leaves, then experiments in transpiration and (on sunny days) photosynthesis, ending with the examination of such flowers as are available; water-cultures are started with seedlings. The third term (April to June) begins with the study of opening buds, of flowers (with special reference to pollination); then come further physiological experiments and microscopic work; soils are examined; the study of Bacteria, Yeast, and Moulds affords the basis for an account of the biology of the soil; the study of various plants in flower leads to a discussion of evolution and classification, and the session's work ends with the study of Plant Ecology, with excursions to heaths, woods, ponds and streams, chalk-downs, and sea-coast.

In this Appendix I have tried to help the student working alone, who may be starting with the study of Botany, and feel bewildered by the mass of material met with in taking up even an elementary book like this. At whatever time of year you begin, I would strongly advise you to work through the book in the order of the chapters. If you cannot get Broad Bean plants, use the Wallflower; much of Ch. I. applies to any ordinary flowering-plant. Begin at once with work on seeds and their germination, and use the seedlings for experiments on the directive effect of gravity, light, and moisture, on transpiration, the path of the water and salts absorbed by the root, photosynthesis, also for structure of root, stem, and leaf. Abundant material for study of shoots can be obtained at any time of year, either growing wild or in greenhouses, or from the greengrocer and the seedsman or nurseryman (see under October,

November, and December). Ch. V. should only be read after the experiments in the earlier chapters have been done; it may be omitted, if time presses, until the later chapters are worked through. Then get some flowers and fruits and work through as much of Ch. VI. and Ch. VII. as possible. This will enable you to become acquainted with a few of the Natural Orders, and (which is of greater importance) the adaptations of flowers for pollination and those of fruits and seeds for dispersal. Next study the adaptation of plants to special localities, the characters of the chief Natural Orders, and the evolution of plants which is the basis of classification and which is closely connected with their adaptations and their distribution.

If you are a beginner in Botany, do not attempt to acquire systematic knowledge of the orders, genera, and species of flowering-plants until you have worked thoroughly through the structure, and especially the physiology, of plants. The notes given in Ch. IX. and in App. III. will help you to identify the plants met with in such special localities as bogs or salt-marshes, since it is necessary to recognise the characteristic plants in such "associations." Few students realise how great a stock of knowledge of plants, as regards structure, physiology, and adaptations of their vegetative and reproductive organs, can be acquired by using a few plants which every one knows by name, and without "getting up" a vocabulary of technical terms. Later on, however, get a *Flora* or Fox's book (see p. 340), and identify all the plants in flower which you meet with; in this work, the lists given under the various months will be of some help. These lists have been made from diaries kept for several years, chiefly in South Hampshire and South Devon, so that students living in the North of England or in Scotland may not meet with the flowers of these plants until several weeks after they begin to flower in the extreme south.

Microscope-work, if not allowed to occupy time which would (in the case of a beginner) be better spent in making physiological experiments and in studying flowers, fruits, plant-associations, etc., is valuable in helping one to understand more fully the structure of plants, especially if minute structure is studied in close connection with physiology. A good microscope can be obtained for £5.* The following apparatus is necessary for microscope-work:

(*a*) A good razor, slightly hollow ground;
(*b*) Glass slides, 3 in. × 1 in., and cover-glasses $\frac{7}{8}$ in. diameter or square;
(*c*) Small forceps, mounted needles (made by fixing a needle, point outwards, into one end of a penholder);
(*d*) A few watch-glasses, small brushes, and a clean piece of soft linen;

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* Particulars of microscopes and dissecting instruments can be obtained from Clive & Co., 48, Southampton Row, London, W.C.

(*e*) Pickle jars, methylated spirit, formalin;

(*f*) Small bottles (with dipping rods) containing iodine solution (iodine tincture diluted with water), aniline sulphate (or chloride), glycerine.

Fresh material may be used for microscope-work, but it is often better to use "pickled" material. The pickling fluid used for ordinary work is methylated spirit (alcohol), diluted with about half its volume of water. Stems, roots, leaves, etc., preserved in this way in glass jars are always ready for use. Delicate plants or parts of plants (flowers, etc.) may be preserved in 4 to 6 per cent. solution of formalin (formaldehyde); formalin as sold is a 40 per cent. solution.

In taking a section, the tissue to be cut should be held between the thumb and fingers of the left hand; the razor in the right hand. The tips of the four right fingers should rest on the back of the razor, and the thumb in front, just behind the cutting edge. The cutting edge is therefore directed inwards, towards the operator. The arms should be brought close up to the body. Tissue and razor should both be wet with alcohol. The blade of the razor may rest gently on the forefinger of the left hand with the edge against the tissue. Then the razor should be drawn through the tissue with a sliding movement. *With practice*, extremely thin sections may be cut.

The sections should be removed from the razor by means of a brush, and placed in a watch-glass containing alcohol or water. Several may then be transferred to a slide and examined in water under the low power, so that the best may be selected. By means of the linen rag the excess of water may be removed, and iodine or other reagent added according to the special points which the student wishes to determine. The reagent should then be washed off with water, the excess of water removed, a drop of glycerine added, and finally the cover-glass put on. The section should always be mounted in the centre of the slide. The cover-glass should be rested on its edge and let down gradually by means of a needle. The section *must not be allowed to get dry* during the process, or air-bubbles will make their appearance. If these do appear, soaking the section for some time in alcohol will remove them. The cover-glass must be perfectly clean, and the upper surface dry.

Neatness and cleanliness are of great importance in practical work. At first the student will find that his sections are rather thick, and often obliquely cut. These are difficulties which can be got over only by care and practice. He should not attempt to draw a bad section.

Very slender or delicate tissues should be cut by embedding in pith or carrot. If carrot be used, a piece 1 in. × ½ in. × ¼ in. will be found convenient.

SEPTEMBER.

Plants of Broad Bean (Ch. I.) may be obtained, but most varieties will be in fruit now. Start work on seeds and their germination, making as many as possible of the experiments in Ch. II. Begin daily observations on temperature, barometric pressure (plot daily readings in a "curve"), humidity, rainfall, and weather notes.

Gather perennial plants for study of shoot, root-system, leaves (arrangement, shape, etc.), giving special attention to rhizomes, runners, cladodes (Butcher's Broom, Asparagus), spines (Hawthorn, Gorse), prickles (Bramble, Rose), suckers (Dead-nettles, Mints, Raspberry); also examine, sketch, and test for stored food the rhizomes, bulbs, and corms of Iris, Solomon's Seal, Narcissus, Tulip, Hyacinth, Snowdrop, Crocus, etc.

Examine the flowers of any wild or garden plants now available; some of the plants listed for the summer months may still be found in flower.

OCTOBER.

Continue work on seeds, germination, and shoots. Collect fruits for study of their structure, with special reference to seed-dispersal—*e.g.* Ash, Maple, Sycamore, Clematis, Dandelion, Groundsel, Thistles, Willow-herb, Burdock, Cleavers, Agrimony, Geranium, Yew, Mistletoe; arrange the dry fruits according to structure or to their mode of dispersal (Ch. VII.). Examine twigs of common trees (Ch. IX.), making a sketch of each showing its external characters (Exp. 326), so as to be able to recognise each tree (if deciduous) after its leaves have fallen.

Examine any wild flowers now obtainable—*e.g.* Ivy, Dwarf Gorse, White Horehound, Wood Sage—and any cultivated flowers in gardens or greenhouses; also fruits of Rowan, Spindle-tree, Holly, Rose, Hawthorn, etc.

Watch farm-yard operations each month; about this time there is sowing of early wheat, ploughing, manure-carting.

NOVEMBER.

Continue the October work. Get common fruits and vegetables from shops for examination of structure (Almond, Apple, Banana, Brazil-nuts, Cranberries, Damson's, Fig, Filberts, Grapes, Lemon, Melon, Orange, Pomegranate; Artichokes, Beet-root, Brussels Sprouts, Carrots, Cauliflower, Celery, Cucumber, Horseradish, Mushrooms, Onion, Parsnip, Potato, Tomato, Turnip).

Plants in flower: Jasmine, Christmas Rose, and other cultivated plants; also a few wild plants in sheltered places.

DECEMBER.

During the next three months a good deal of bookwork should be done; but most of the experiments in plant-physiology can be made, especially on sunny days in the case of photosynthesis and transpiration.

Continue previous work on shoots, fruits, seeds, germination; pay special attention to reserve-foods and their digestion, root-absorption paths, by which water ascends in root and shoot. Examine trees in the leafless condition, noting the general appearance, mode of branching, directions of growth of upper and lower branches, leaf-scars, buds, lenticels, etc., and examine the structure of the buds.

Read parts of text-book dealing with water, air, soil; also Ch. IX.

This is a suitable time for microscopic work on seeds, stems, roots, leaves. If a microscope is not available, however, much can be done with a good lens (see "Hints on Lens Work" in Ch. I.).

JANUARY.

Continue the work on seeds and seedlings, root, shoot; common plants, shop vegetables and fruits, and greenhouse material should be used for examination of structure (make notes and sketches).

Much outdoor observation can be done at this time, though few plants are in flower. Observe, and account for, the difference between trees with pointed tops ("excurrent" habit) and trees with rounded tops ("deliquescent" habit); the turned-up ends of the lower branches of many trees; the differences between the north and south sides of exposed trees; the shape of trees growing singly on wind-swept ridges, or near the sea; the way in which trees cover up wounds caused by broken-off branches. Notice the leaf-carpet of woods, the formation of leaf-mould (scrape or dig to see how deep it is, and examine its structure); the ways in which the young leaves of perennial herbaceous plants are packed, and how they unfold and spread out.

Plants in flower *: Snowdrop, Winter Aconite, Green Hellebore, Christmas Rose, Chickweed, Shepherd's Purse, Groundsel, etc.

FEBRUARY.

On sunny days try the experiments on transpiration and photosynthesis (Ch. IV.) and read Ch. VIII.

Watch farm operations—*e.g.* ploughing, carting of manure and

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* Remember that these lists are made from observations in the south of England (Hampshire, Devonshire), and that most of the plants named continue in flower for some time after the months in which they are listed.

lime, "hedging and ditching"—and read parts of Ch. III. dealing with soils, manures and fertilisers; examine soils, and compare them as to absorption and retention of water, size of soil-grains, etc.; read parts of Ch. III. dealing with tilth and tillage.

Plants in flower (see January list): Hazel, Stinking Hellebore, Barren Strawberry, Gorse, Spurge Laurel, Red Dead-nettle, Butterbur.

MARCH.

Read Ch. VI., noting especially the characters of common Orders and those of wind-pollinated flowers. Continue work on shoots and leaves, examine buds of trees and shrubs, and carry on experiments on photosynthesis, etc. (Ch. II. to Ch. IV.). Begin systematic work on Natural Orders, using a *Flora*, and refer to App. III. in order to see the relationship between the Orders.

Plants in flower (see January and February lists): Yew, Field Woodrush, Butcher's Broom, Daffodil, Crocus, Sallow and Goat Willow, Aspen Poplar, Common and Wych Elms, Little Mouse-ear Chickweed (*Cerastium semidecandrum*), Lesser Celandine, Wood Anemone, Marsh Marigold, Whitlow Grass, Hairy Bittercress, Golden Saxifrage, Sloe, Wood Spurge, Dog's Mercury, Sweet and Dog Violets, Mezereon, Lesser Periwinkle, Field and Ivy-leaved Speedwells, Moschatel, Coltsfoot, Daisy, Dandelion.

APRIL.

More material is now available for work on leaves and their arrangement, "leaf-mosaics"; creeping, climbing, and rosette-forming plants. Look for seedlings of Gorse and other plants. Watch the bursting of buds and the unfolding of leaves; bring cut twigs indoors, set them in water, and watch daily. Continue work on structure and pollination of flowers. Read Ch. IX. in preparation for field-work on plant ecology (distribution and adaptation to surroundings).

Plants in flower (see preceding lists): Arum, Broad Hairy Woodrush (*Luzula pilosa*), Bluebell, Broad-leaved Garlic, Early Purple Orchis, Poplars (Black and White), Birch, Beech, Oak, Mistletoe, Sheep's Sorrel, Broad-leaved, Field, and Common Mouse-ear Chickweeds (*Cerastium glomeratum*, *C. arvense*, *C. triviale*), Greater Stitchwort, Red Campion, Pasque-flower, Goldilocks, Mousetail, Common Fumitory (*Fumaria officinalis*), Cuckoo-flower, Scurvy-grass, Garlic, Mustard, Smooth Pepperwort (*Lepidium smithii*), Rue-leaved Saxifrage (*Saxifraga tridactylites*), Wild Cherry, Water Avens, Geraniums (Herb Robert, Soft, Shining), Wood Sorrel, Box, Crowberry, Marsh and Hairy Violets (*Viola palustris*, *V. hirta*), Wild Beaked Parsley (Chervil), Ash, Great Periwinkle, Yellow and Blue

Scorpion-grass (*Myosotis versicolor*), White Dead-nettle, Yellow Dead-nettle (Archangel), Ground Ivy, Toothwort, Speedwells (Buxbaum's, Wall, Germander), Crosswort Bedstraw, Field Madder, Lamb's Lettuce.

MAY.

From this point only lists of plants that come into flower each month will be given. Indoor work on the structure of shoots, roots, flowers, and fruits, on seeds and their germination, on physiology, water-cultures, etc., should be continued, but as many outdoor observations as possible should be made, in order to gain a thorough acquaintance with Plant Ecology, the study of plants in their homes. At the same time, study the mode of growth of the different plants met with, the arrangement and form of the leaves, the structure and biology of the flowers, the fruits and methods of seed-dispersal.

Make observations on the biology of inflorescences and flowers. For instance, examine and record the various cases of flat-topped inflorescences met with, noting that plants with inflorescences of this kind ("shield-bearers") are found in many different Orders—*e.g.* Cruciferae (Candytuft, etc.), Rosaceae (Cherry, Rowan, Meadowsweet, Hawthorn, etc.), Leguminosae (Clovers, *Lotus*, etc.), Umbellifers, Ivy, Dogwood, Elder, Valerians, Dipsaceae, Sheep's-bit, Compositae, etc.

So many plants are now coming into flower that the lists for the next four months are limited to the more widely distributed or especially noticeable plants. Grasses and Sedges are omitted, because they are mostly too difficult for a beginner; other large and rather monotonous Orders—*e.g.* Cruciferae, Umbelliferae, Compositae—have been greatly cut down in making these lists.

When the Orders are fairly mastered, try to identify the commoner species in the larger genera—*e.g.* Ranunculus, Hypericum, Geranium, Trifolium, Potentilla, Rosa, Epilobium, Veronica, Galium, Rumex, Polygonum; note the differences in vegetative organs, flowers, time of flowering, habitat, etc.

Plants in flower (see March and April lists): Pine, Juniper, Sea Arrowgrass, Great Woodrush (*Luzula sylvatica*), Lily of the Valley, Solomon's Seal, Herb Paris, Black Bryony, Yellow Iris, Twayblade (*Lister ovata*), Helleborine Orchids (*Cephalanthera grandiflora*, *C. ensifolia*), Green-winged Orchis (*Orchis morio*), Dwarf Orchis (*O. ustulata*), Marsh Orchis (*O. latifolia*), Spotted Orchis (*O. maculata*), Bee Orchid (*Ophrys apifera*), Spanish Chestnut, Hornbeam, *Asarum* (rare), Pearlworts (*Sagina procumbens*, *S. apetala*, *S. maritima*, *S. ciliata*), Sandworts (*Arenaria trinervia*, *A. serpyllifolia*, *A. peploides*), Chickweeds (*Cerastium tetrandrum*), Stitchworts (*Stellaria graminea*, *S. uliginosa*), White Campion, Ragged Robin, Buttercups (Marsh, Ivy-leaved, Meadow, Creeping, Bulbous, Celery-leaved, Corn), Columbine, Barberry, Poppies (Red, Rough, Long-headed), Greater

Celandine, Yellow Fumitory, Water-cress, Charlock, Hairy Rock-cress, Sea Rocket, Thale-cress, Field Penny-cress, White Meadow Saxifrage (*S. granulata*), Hawthorn, Wild Strawberry, Bird Cherry, Rowan, Tormentil, Burnet-leaved Rose (*R. spinosissima*), Common and Field Lady's Mantle (*Alchemilla vulgaris, A. arvensis*), Broom, Petty Whin, Black Medick (*Medicago lupulina*) and Spotted Medick (*M. maculata*), Clovers (White, *Trifolium repens*; Purple, *T. pratense*; Zigzag, *T. medium*; Hop Trefoil, *T. procumbens*), Bird's-foot (*Ornithopus*), Horse-shoe Vetch (*Hippocrepis*), Common Vetch (*Vicia sativa*), Bitter Vetch (*V. orobus*), Bush Vetch (*V. sepium*), Tuberous Vetch (*Lathyrus macrorhizus*), Grass Vetch (*L. nissolia*), Geraniums (Cut-leaved, Dusky), Stork's-bill, Milkwort, Holly, Spindle-tree, Maple, Sycamore, Common and Alder Buckthorns, Marsh Pennywort, Wood Sanicle, Earth-nut (*Bunium flexuosum*), Samphire (*Crithmum*), Sweet Cicely (*Myrrhis*), Yellow Wood Loosestrife, Water Violet, Scarlet Pimpernel, Sea Thrift, Bog Bean, Tufted Water Scorpion-grass (*Myosotis caespitosa*), Corn Gromwell, Comfrey, Alkanet, Wild Sage (Clary), Bugle, Henbit Dead-nettle, Corn Woundwort (*Stachys arvensis*), "Tea-plant" (*Lycium*, not native), Speedwells (*Veronica officinalis, V. serpyllifolia, V. beccabunga*), Eyebright, Yellow Rattle, Field and Marsh Louseworts, Ivy-leaved Toadflax, Greater Broom-rape, Greater and Ribwort Plantains, Sweet Woodruff, Wayfaring Tree, Marsh Valerian (*V. dioica*), Red Valerian (*Centranthus*), White Bryony, Mouse-ear Hawkweed.

JUNE.

Plants in flower (see April and May lists): Branched Bur-reed, Broad-leaved Pondweed (*Potamogeton natans*), Marsh Arrowgrass, Water Plantain, Flowering Rush, Stinking Iris, Orchids (Bird's-nest, Heart-leaved Twayblade, Pyramidal, Fragrant, Butterfly, Frog, Fly), Bog Myrtle, Greater Nettle, Wall Pellitory, Knotgrass, Docks, Good King Henry, Wild Beet, Bladder and Sea Campions, Yellow and White Water-lilies, Greater and Lesser Spearworts, Yellow horned Poppy, White Climbing Corydalis (*C. claviculata*), Sea Rocket, Sea Kale, Wart-cress (*Senebiera coronopus*), Hedge Mustard (*Sisymbrium officinale*), Sea Radish, White and Common Mustards (*Sinapis alba, S. nigra*), Wild Mignonette, Rose-root (*Sedum rhodiola*), Biting Stonecrop, Wall Pennywort, Meadow-sweet and Dropwort (*Spiraea ulmaria, S. filipendula*), Wood Avens, Creeping Cinquefoil, Silver-weed, Purple Marsh Cinquefoil (*Comarum palustre*), Wild Raspberry, Dog Rose, Trailing Rose (*R. arvensis*), Agrimony, Great Burnet (*Sanguisorba officinalis*), Salad Burnet (*Poterium sanguisorba*), Dyer's Greenweed (*Genista tinctoria*), Kidney Vetch (Lady's-fingers), Lesser Yellow Trefoil (*Trifolium dubium*), Bird's-foot Trefoil (*Lotus corniculatus*), Wood Vetch (*Vicia sylvatica*), Tufted Vetch (*V. cracca*), Meadow Vetchling (*Lathyrus pratensis*), Wood, Blue Meadow, Small-flowered, Mountain, Long-stalked, and Bloody

Crane's-bills (*Geranium sylvaticum*, *G. pratense*, *G. pusillum*, *G. pyrenaicum*, *G. columbinum*, *G. sanguineum*), Cathartic and Perennial Flaxes, Sun Spurge, Lime-tree, Dwarf and Common Mallows (*Malva rotundifolia*, *M. sylvestris*), Tutsan and Small St. John's Worts (*Hypericum androsaemum*, *H. pulchrum*), Purple Loosestrife, Enchanter's Nightshade, Hemlock (*Conium maculatum*), Wild Celery (*Apium graveolens*), Small Marsh-wort (*Helosciadium inundatum*), Gout-weed (*Aegopodium podagraria*), Cow Parsnip (*Heracleum*), Wild Carrot (*Daucus carota*), Shepherd's Needle (*Scandix*), Rough Chervil (*Chærophyllum temulum*), Lesser Winter-green (*Pyrola minor*), Moneywort (*Lysimachia nummularia*), Brook-weed (*Samolus*), Sea Milkwort (*Glaux*), Bastard Pimpernel (*Centunculus*), Centaury (*Erythraea*), Yellow Gentian (*Chlora*), Great, Small, and Sea Bindweeds (*Convolvulus sepium*, *arvense*, *soldanella*), Water Forget-me-not and Field Scorpion-grass (*Myosotis palustris*, *M. arvensis*), Viper's Bugloss (*Echium vulgare*), Borage, Bugloss (*Lycopsis arvensis*), Hound's-tongue, Gromwell (*Lithospermum officinale*), Thyme, Black Horehound (*Ballota nigra*), Hedge Woundwort (*Stachys sylvatica*), Henbane, Black and Bittersweet Nightshades (*Solanum nigrum*, *S. dulcamara*), Deadly Nightshade (*Atropa*), Water and Knotted Figworts (*Scrophularia aquatica*, *S. nodosa*), Foxglove, Lesser Broomrape (*Orobanche minor*); Butterworts, Bladderworts, Hoary, Sea, and Buck's-horn Plantains (*Plantago media*, *P. maritima*, *P. coronopus*); Yellow, Heath, and Goosegrass Bedstraws (*Galium verum*, *G. saxatile*, *G. aparine*), Common and Dwarf Elders (*Sambucus nigra*, *S. ebulus*), Guelder Rose, Honeysuckle, Great Valerian (*V. officinalis*), Field Scabious (*S. arvensis*), Goat's-beard, Bristly Ox-tongue (*Helminthia*), Rough Hawkbit (*Leontodon hispidus*), Cat's-ear (*Hypochaeris radicata*), Wall Lettuce, Common Sow-thistle (*Sonchus oleraceus*), Carline Thistle, Knapweed and Bluebottle (*Centaurea nigra*, *C. cyanus*), Cudweed (*Antennaria dioica*), Common Ragwort (*Senecio jacobaea*), Ox-eye Daisy, Stinking Chamomile (*Matricaria chamomilla*), Scentless Mayweed (*Matricaria inodora*), Corn Marigold (*Chrysanthemum segetum*), Milfoil (*Yarrow*).

JULY.

Plants in flower (see June list): Greater and Lesser Bulrushes, Unbranched Bur-reed, Arrowhead (*Sagittaria*), various Rushes (*Juncus communis*, *bufonius*, *acutiflorus*, *lamprocarpus*, *squarrosus*, *glaucus*), Crow Garlic (*Allium vineale*), Bog Asphodel (*Narthecium*), Broad-leaved Helleborine (*Epipactis latifolia*), Small Nettle (*Urtica urens*), Hop; Polygonums (*P. persicaria*, *P. convolvulus*, *P. amphibium*, *P. lapathifolium*), Docks (*Rumex crispus*, *R. obtusifolius*, *R. conglomeratus*, *R. sanguineus*, *R. hydrolapathum*), White Goosefoot (*Chenopodium album*), Oraches (*Atriplex hastata*, *A. patula* *A. laciniata*, *A. portulacoides*), Saltwort, Sea-blite, Marsh Samphire,

Corn Cockle, Pearlworts (*Sagina nodosa*, *S. subulata*), Corn Spurrey, Sandwort Spurreys (*Spergularia*), Traveller's Joy (*Clematis*), Meadow-rues (*Thalictrum minus*, *T. flavum*), Monkshood, Sundews (*Drosera rotundifolia*, *D. intermedia*, *D. anglica*), Orpine (*Sedum telephium*), House-leek, Brambles, Downy-leaved and Sweet-brier Roses (*Rosa villosa*, *R. rubiginosa*), Common Melilot (*Melilotus officinalis*), Hare's-foot Trefoil (*Trifolium arvense*), Hairy Tare (*Vicia hirsuta*), Dwarf Autumn Gorse (*Ulex nana*, S. Eng.), All-seed (*Radiola*), Spurges (*Euphorbia peplus*, *E. Exigua*, *E. paralias*), Musk Mallow, St. John's Worts (*Hypericum quadrangulum*, *H. perforatum*, *H. humifusum*, *H. hirsutum*, *H. dubium*, *H. elodes*), Rose of Sharon (*Hypericum calycinum*, not native), Willow-herbs (*Epilobium parviflorum*, *E. montanum*, *E. palustre*, *E. tetragonum*, *E. angustifolium*, *E. hirsutum*), Sea Holly, Procumbent Marshwort (*Helosciadium nodiflorum*), Broad- and Narrow-leaved Water-parsnips (*Sium latifolium*, *S. angustifolium*), Burnet Saxifrage (*Pimpinella*), Water Dropworts (*Oenanthe fistulosa*, *crocata*, *lachenalii*), Fool's Parsley (*Aethusa*), Fennel (*Foeniculum*), Samphire (*Crithmum*), Angelica, Wild Parsnip (*Pastinaca*), Hedge Parsley (*Caucalis anthriscus*), Ling (*Calluna*), Cross-leaved and Bell Heathers (*Erica tetralix*, *E. cinerea*), Great Yellow Loosestrife (*Lysimachia vulgaris*), Bog Pimpernel (*Anagallis tenella*), Sea Lavender (*Statice*), Field Gentian (*Gentiana campestris*), Dodder (*Cuscuta*), Gipsy-wort (*Lycopus*), Marjoram (*Origanum*); Common, Basil, and Basil-Thyme Calamints; Cat Mint (*Nepeta cataria*), Wood Sage (*Teucrium scorodonia*), Self-heal (*Prunella*), Skull-cap (*Scutellaria*), White Horehound (*Marrubium*); Corn and Marsh Woundworts (*Stachys arvensis*, *S. palustris*), Wood Betony (*Stachys betonica*), Hemp-nettle (*Galeopsis tetrahit*), Woolly Mullein (*Verbascum thapsus*), Marsh and Water Speedwells (*Veronica scutellata*, *V. anagallis*), Bartsia, Common Toadflax, Snapdragon, Monkey-flower (*Mimulus luteus*, garden escape), Plantain Shoreweed (*Littorella*), Bedstraws (*Galium palustre*, *G. uliginosum*, *G. mollugo*), Snowberry (*Symphoricarpus*, garden escape), Devil's-bit Scabious (*Scabiosa succisa*), Small Scabious (*S. columbaria*), Hare-bells (*Campanula rotundifolia*, *C. latifolia*, *C. trachelium*, *C. hederacea*), Hawkweed Picris, Hemp Agrimony (*Eupatorium*), Hairy Hawkbit (*Leontodon hirtus*), Smooth-leaved Hawk's-beard (*Crepis virens*), Marsh Crepis, various Hawkweeds (*Hieracium*), Nipplewort (*Lapsana communis*), Chicory (*Cichorium intybus*), Burdock, various Thistles (*Carduus*, *Cnicus*), Sneezewort (*Achillea ptarmica*), Mugwort and Wormwood (*Artemisia vulgaris*, *A. absinthium*), Hard-heads (*Centaurea scabiosa*), Bur Marigold (*Bidens*), Marsh Ragwort (*Senecio aquaticus*), Wood and Marsh Cudweeds (*Gnaphalium sylvaticum*, *G. uliginosum*), Ploughman's Spikenard (*Inula conyza*), Golden Samphire (*Inula crithmoides*), Golden Rod, Sea Daisy (*Aster tripolium*), Flea-bane (*Pulicaria*).

AUGUST.

Plants in flower (see June and July lists): Meadow Saffron (*Colchicum*), Autumn Lady's-tresses (*Spiranthes*), Bog Orchis (*Malaxis paludosa*), Water Pepperwort (*Polygonum hydropiper*), Goosefoots (*Chenopodium rubrum, polyspermum, urbicum, glaucum, vulvaria*), Soapwort (*Saponaria officinalis*, not native), Grass of Parnassus (*Parnassia*), Annual Mercury, Marsh Mallow (*Althaea officinalis*), Tamarisk and Frankenia (south and east coast of Eng.), Stone Parsley (*Sison amomum*), Small-flowered and Marsh Gentians (*Gentiana amarella, G. pneumonanthe*), Mints (*Mentha aquatica, M. arvensis, M. sativa, M. piperita, M. sylvestris, M. rotundifolia*), Pennyroyal (*Mentha pulegium*), Teasel (*Dipsacus sylvestris*), Clustered Bell-flower (*Campanula glomerata*), Tansy (*Tanacetum*), Autumn Hawk-bit (*Leontodon autumnalis*), Shrubby Hawkweed (*Hieracium boreale*), Corn Sow-thistle (*Sonchus arvensis*), Saw-wort (*Serratula*).

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